IBC 'Oil and Gas Developments in West Africa', London, 25-26 October 1999

Exploration Opportunities in Offshore Deepwater Africa

N.R. Cameron (consultant to TDI-Brooks International, Inc.)
and
Ken White (EIS Energy Information Services Ltd.)

The West African deepwater is, as is evident from the just subsided bidding "frenzy" for Angola Blocks 31-33 and the growing excitement generated by the Agbami giant in Nigeria and now the La Ceiba find in Rio Muni, of global importance to the oil industry. The objectives of this contribution are to examine, in terms of the regional geological framework, why the West African deepwater (Angola to Ivory Coast) is of such interest and to suggest what the future could hold for this already exceptionally rewarding region (Knight and Westwood, 1999).

The traditional onset of the deepwater is the 200-metre (660-feet) shelf edge isobath. Increasingly, the deepwater commences at the 500 metres (1640 feet) isobath with the ultra-deepwater commencing at 1500 metres (4920 feet). Now, as the exploration and technology horizon advances oceanwards, terms such as ultra-ultradeepwater are emerging for the 2500 metres (8200 feet) plus frontier. These distinctions are not utilised in this review and all water depths greater than 200 metres are referred to as deepwater.

To provide adequate space to present the great variety of geological settings, only passing reference is made to existing, developing and planned deepwater production facilities. Other contributors to this conference will be addressing some of these developments. Emphasis is placed on Angola since this where the main discoveries have been. However, as will be argued, Nigeria seems to be destined to become a second focus.

Why is the West African deepwater so exciting?

Excitement with the deepwater of West Africa was finally unleashed, following the discovery in 1984/85 of the first Campos Basin fields of Brazil in settings that could be readily shown to re-occur along much of the eastern margin of the Atlantic Ocean. The primary targets were high deliverability giants associated with thick, mainly young Tertiary (Neogene) sands positioned either in base of slope sheet settings or in up-slope feeder channels. Systematic deepwater exploration commenced in the Congo Basin of Angola in 1994 and in 1997 the annual reserve additions, as shown on Figure 1 (Cameron *et al.*, 1999), were more than double the best rates previously achieved for the southern West Africa region (Gabon to Angola). Key events are included. An identically shaped plot arises when the entire margin from Angola to the Ivory Coast is considered, though in this case the deepwater peak, at least up to mid-1998, is less dramatic due to the size of the delta top discoveries in Nigeria during the 1960s. The impact for Angola of the deepwater discoveries in terms of the traditional ("classic") play settings and their reserves is illustrated on Figure 2. As can be seen the Tertiary contributed less than 5% of the reserves five years ago. The percentage is currently 35% and continuing to rise rapidly.

Prior to the deepwater successes, the largest oil field in southern Africa outside Nigeria was Rabi-Kounga (1985) in Gabon with reserves of 1100 MMbo. The second largest field was Takula (1971) in Cabinda with 750 MMbo. Only fourteen more fields in Gabon, the Congos and Angola had reserves in excess of 200 MMbo, the remaining fields, despite forty-five years of often intensive exploration are mostly considerably smaller (as can be seen from Figure 1, the cumulative totals for individual plays and areas are significant). In contrast, for the same area, there have been in only four years at least fifteen deepwater discoveries each of whose reserves are believed to be in excess of 200 MMbo. All of these fields are in Angola. Six may be giants (>500 MMbo) and two (Girassol and Dahlia) are in the 1000 MMbo plus class. Success rates have been exceptional with all the Angolan deepwater blocks so far drilled, except for Shell's 16 and Mobil's 20, yielding either announced commercial (Blocks 14, 15, and 17) or expected to be commercial (Block 18) discoveries. Of great significance has been the regular achievement on test of the high flow potential required for successful deepwater economics. Further comments on the Angolan discoveries, together with those in Congo Brazzaville, and the recently much more encouraging results from Nigeria are provided in the regional profile sections of this paper. Triton's La Ceiba discovery in Rio Muni is also included.

For the record, Shell drilled the first deepwater well in West Africa twenty-five years ago. The target was a "classic" play in Gabon. Since then some 150 exploration wells have been drilled in water depths greater than 200 metres. Ninety of these are located in water depths in excess of 500 metres. The deepest utilised water depth to date is 1410 metres (4626 feet) at Exxon's Bosi-1 in Nigeria (OPL 209). The world's deepest seabed well is Petrobras' 2-RJS-538 located in 2603 metres (8540 feet) of water in the Campos Basin of Brazil. The deepest water producer is in the Roncador Field also in the Campos Basin. Here the water depth is 1853 metres (6080 feet).

Why is the West African deepwater so prolific?

The answer to this question, as in all of the world's great fairways, is the simplicity of the play elements plus the "icing on the cake" circumstances that always characterise global scale accumulations. The basic play ingredients are: 1) an abundance of rich, commonly oil-prone source rocks, 2) the frequent presence of thick clean sands, 3) young structuring and 4) ongoing hydrocarbons generation. Of these four factors, the most important is the regional development of source rocks throughout much of the target succession (Schiefelbein *et al.*, 1999). The result is that oil is invariably generated wherever there is sufficient sedimentary loading, for example beneath a river delta, for maturity. This diversity and regional spread of sources are only repeated in Brazil and in parts of the Middle East and the Gulf of Mexico. Unlike West Africa, the geographical spread of mature sources in Brazil is less widespread.

The following section examines in more detail the geological setting of the deepwater. It is provided as the play elements vary in their strengths and not all areas can be as prolific as Angola and Nigeria. To understand why a digression into geology, and in particular into the role played by hinge lines and river mega-deltas is required. Because of the shortness of this segment much of the geology has been generalised. To make up for this deficit, references providing infill material are supplied (this is not always easy as comprehensive modern publications only exist for a few areas).

Figures 3a and 3b introduce the geological features controlling the deepwater plays. As will be demonstrated, oceanwards bulges of the isobaths opposite a river mouth are a hallmark of deepwater depocentres. Separation of the isobaths is also an immediate indicator of depocentres. To highlight both these areas, the deepwater exploration swath from 200 to 2500 metre isobaths is shaded. Note that thick sedimentary sections can also be present where the distance between the 200 and 2500 metre isobaths is narrower, but in these areas the range of opportunities is more limited.

Hinge line deepwater settings

Both the African and South American margins of the southern Atlantic are associated with extensional tectonics developed as they were stretched during rifting (Cainelli and Mohriak, 1999). Three sets of tectonic lines resulted. These, moving oceanwards, are the Inland Hinge, the Atlantic Hinge and the Continent-Ocean Boundary (COB). In West Africa these hinges were first identified from Gabon by Anton Brink (1974): Anton was subsequently appointed Vanco's Chief Geologist and his name has been given to one of the company's pair of deepwater blocks in southern Gabon. The track of the hinges has now been determined from seismic and gravity for the entire West African margin, though much of this work remains to be published. The hinges are closest to each other where the margin has been foreshortened by transcurrent (strike slip) faulting as in southern Angola, Equatorial Guinea, Cameroon and west of the Niger Delta. More information on the origin and history of the hinge lines may be found in Karner *et al.* (1997). The paper includes seismic lines. A type seismic section across the Atlantic Hinge in Cabinda (Angola) is provided by Dale *et al.* (1990). We have simplified the traces of the hinge lines in regions of structural complexity.

The existing production lies, apart for the Niger Delta and the Ogooué Fan in Gabon, between the Atlantic and Inland Hinges, much of it directly associated with traps developed above the trace of the Atlantic Hinge. Information on the resulting play types is provided by McHargue (1991) for Cabinda and for Gabon by Teisserene and Villemin (1990). This entire area forms the region of "classic" plays. As will be seen, though the focus of this review is on the younger Tertiary deepwater potential, "classic" play elements also occur in the deepwater where the younger Tertiary cover is insufficient to smoother the older play elements.

Where it is located offshore, the Atlantic Hinge tracks, except in sediment starved regions, the 200 metre shelf edge isobath. As such it defines the incoming of the deepwater exploration frontier and increasingly, following the deepwater successes, the development frontier. The deepwater frontier owes much of its success to the presence of an expanded section oceanwards of the Atlantic Hinge. This expanded section contains, as argued by Cameron *et al.* (1998), a broader suite of Cretaceous and Tertiary source rocks than those developed in the “classic” play areas. Because of their distal setting from the coast many of these source rocks are richly oil-prone. There is also generally a much thicker cover of younger Tertiary (Neogene). Indeed, the younger Tertiary is commonly entirely missing from the “classic” play regions (an exception is the onshore Kwanza Basin where tectonism akin to the deepwater events developed). Their absence equates to onshore regional uplift where associated increasing rainfall resulted in river captures and an abruptly increased supply of sediments to the deepwater. Burke (1996) details the causes of these changes. The thickest and most widespread sands are associated with the Kwanza, Congo, Ogooué and the Niger/Benue Rivers and groupings of smaller but high, in the wet season, flow rate rivers such as those in the southern Kwanza (Benguela) Basin.

Young structuring south of central Cameroon is mainly associated with the oceanwards movement of salt related to the progradation of the fans (Lundin, 1992). From Equatorial Guinea (Rio Muni) to central Cameroon young tectonics related to strike-slip movements are also important (Loader *et al*., 1998; and Bray and Lawrence (1999). West of the Niger Delta young structuring is less evident, except near the Atlantic Hinge and the Atlantic fracture zones.

Where there is sufficient loading, such as on the flanks of the Congo Fan, the marine Cretaceous section has entered and, in some cases, passed through the oil window permitting ready migration of hydrocarbons up active extensional fault traces into the overlying younger Tertiary sands. In the central region of the Congo Fan there is sufficient cover for the source units within the Oligo-Miocene succession to also enter the oil window permitting the development of even more efficient migration pathways. However, biodegradation of the oils may become an issue where shallow reservoirs temperatures are low.

Elsewhere the main risk is insufficient cover for the maturation of the drift succession. In some cases, older rift-related sources will be required. These could belong, as in Angola, to the Pre-Salt lacustrine succession or in the Ivory Coast to Albian mixed marine and lacustrine units. This requirement need not be a major problem given that the Campos Basin giant fields are sourced from the Pre-Salt portion of the Lagoa Feia Formation (Kean, 1999). Source issues are considered in more detail in the regional profiles. Further details on the deepwater plays associated with the Atlantic Hinge may be found in the comprehensive volume of abstracts produced for the AAPG’s International Meeting in Rio de Janeiro, Brazil, in November 1998.

Mega-delta deepwater settings

In three regions of West Africa, namely in the Port Gentil region of Central Gabon, the Douala - Rio del Ray region of Cameroon and the Niger Delta, the Atlantic Hinge passes onshore. In these regions the Atlantic Hinge has been overridden by the volume of sediments delivered to the coast by rivers and the modern shoreline has prograded across previously deepwater settings (Cameron *et al.*, 1999). Longshore drift of sediments has also aided the growth of the deltas.

The resulting present day deepwater plays are generally simpler in that fewer source units are involved. Sand dispersal methods to the deepwater, though, are similar. Young structuring is provided in the deepwater region of the Niger Delta by shale diapirism resulting from the growth of the Delta (Cohen and McClay, 1996) and the displacement by squeezing of the sediment pile oceanwards. Upfolds associated with the frontal toe thrust (Doust and Omatsola, 1990; and Morgan, 1999) of the delta complex present major opportunities for the future – these mostly lie, except along the border with Equatorial Guinea, in plus or minus 3000 metres of water. Growth structures akin to those in the onshore Niger Delta provide the targets in the Douala Sub-basin of Cameroon. Active generation is taking place in both areas from Tertiary and younger Cretaceous source rocks.

In Gabon, the primary population of offshore fields (Anguille, Grondin etc.) is associated with deepwater sands related to late Cretaceous (Senonian) drainage changes in the Ogooué River basin triggered by regional tectonism in Africa. Salt tectonism associated with younger Tertiary loading created the traps (Brink, 1974; and Teisserene and Villemin, 1990). Though these discoveries (1500 MMbo in total) were drilled from modern shallow water settings and can, therefore, be considered as “classic” plays, they represent the first fields in West Africa related to depositionally deepwater settings. As such they provide excellent analogues for the younger Tertiary deepwater plays. They may also prove to be useful for modelling Cretaceous deepwater plays in onshore Nigeria and in offshore deepwater Benin and Togo.

The Congo Fan all but overrides the Atlantic Hinge in northern Angola and Congo Kinshasa. Had it not been for the huge volumes of sediments removed into deep ocean settings during the Pleistocene through the cutting of the Congo Canyon, the Atlantic Hinge in this region today would almost certainly be positioned onshore.

Ocean crust and its exploration implications

The Continent-Ocean Crust Boundary (COB) commonly lies between 150 and 250 kilometres offshore in water depths commonly in excess of 2500 metres. It is closest to the Atlantic Hinge, as is evident on Figure 3a and 3b, in the regions of transcurrent faulting. Though source units are present in many South Atlantic DSDP (Deep Sea Drilling Project) holes, for example DSDP 364 and 365 in the Benguela region of

Angola, the sedimentary cover above ocean crust tends to be generally thin and is invariably immature.

Ocean crust is overlain by thick cover in three main areas:

1) the outer Congo Fan of northern Angola (west of the new Blocks 31-34), the far south west of Congo Brazzaville and the Astrid Marin Block of southern Gabon,
2) Central Gabon north of 2º South (technically north of the N'Komi Fracture Zone [not shown on Figure 3]) to Cameroon and
3) the Niger Delta.

As is the case with the Atlantic Hinge, ocean crust extends beneath the onshore Niger Delta, but its track is unclear.

Other than north of the Niger Delta's toe thrust, the sedimentary cover in all the three areas listed above tends to be little deformed except close to the Atlantic fracture zones and in regions of young compressional tectonism. Young volcanic arching is also present in São Tome (Meyers and Rosendahl, 1991) and Equatorial Guinea waters. There is commonly a dramatic jump in the intensity of tectonism immediately landward of the COB, especially where salt is present in the cover section.

Newly acquired speculative seismic on show at industry symposia suggests that thick and extensive sands are present in all three areas of thicker cover. This seismic also suggests that there should be sufficient cover in the depocentre regions to permit maturity in the oldest marine Cretaceous source units. These will be Albian, possibly also youngest Aptian in age. Forced maturation related to young volcanism and/or hot fluid migration near fracture zones may aid maturation locally. In some cases, as noted by Cornford *et al.* (1999), overcooking of the source units may result. Fortunately, these severe events tend to mainly affect the "classic" plays. They also tend to be related to the transcurrent fault zones.

Away from the structured zones, large basin floor fans will be the targets. The tests will be primarily stratigraphic. How to explore for these objectives is beginning to attract serious attention (Worrall *et al.*, 1999). The water depths associated with these opportunities are in the following ranges:

1) 1000 to 3000 plus metres in southern Angola,
2) 2500 to 4000 metres in northern Angola/Congo Brazzaville,
3) 500 to 3000 metres in Central Gabon,
4) 1000 to 20500 metres in Rio Muni/Cameroon and
5) 3000 metres plus in the border region of Nigeria and São Tome.

The regional profiles

Five regional profiles are presented: 1) Central Angola (Benguela fans) to Congo Brazzaville, 2) Gabon, 3) Equatorial Guinea (Rio Muni) to Cameroon, 4) Nigeria/Cameroon (Rio del Ray)/Equatorial Guinea/São Tome and 5) Ghana to the Ivory Coast.

The Central Angola (Benguela fans) to Congo Brazzaville profile

As schematically illustrated on Figure 4, three young Tertiary depocentres are present. The Congo Fan, which is the site of all the deepwater exploration to date apart from Mobil's Block 20 wells, is the dominant feature (Reynaud *et al.*, 1998). The Kwanza Fan to the south is also well developed, but is considerably smaller in size. Typically, because of the smaller volume of sediments involved and the younger timing of the salt tectonics, the Kwanza Fan depocentres are dispersed and are associated with individual salt withdrawal basins (Lundin, 1992). The third depocentre comprises a complex of smaller fans related to rivers such as the Catumbela which enter the sea to the north and south of the cities of Lobito and Benguela. These rivers, as previously mentioned, though small in comparison to the Kwanza carry enormous volumes of sand during the short but intense rainy season. Their cumulative supply of sand to the offshore may, therefore, be of the same magnitude as that of the Kwanza.

The Congo Fan

Three tectonic regimes characterise the deepwater portion of the Congo Fan. These comprise:

1) an eastern province created by extensional salt tectonics and positioned immediately oceanwards of the Atlantic Hinge,
2) a central compressional province and
3) a little deformed province located west of the salt front and deposited above oceanic crust.

Though little has been shown outside international meeting talks and poster displays, Jackson *et al.* (1998) provide an excellent conceptual section of the resulting geology. Regimes 1) and 2) are related to the oceanwards sliding of salt that was initiated at the time of the younger Tertiary (Neogene) growth of the fan. Angola Blocks 14-18 are associated with Regime 1. Angola Blocks 31-34 are dominated by Regime 2. Regime 2 has yet to be drilled, Regime 3 has yet to be licensed.

By mid-1998 and the time of the preparation of Figure 1, some 4500 MMbo of oil had been discovered in the Congo Fan, mostly in Blocks 14 (Chevron, c. 1000 MMbo), 15 (Exxon, c. 1000 MMbo) and 17 (Elf, c. 2500 MMbo). Since then some 2500 MMbo of additional oil have been announced. The true size of the existing discoveries may prove to be much larger, especially in Elf's Block 17. The most significant latest successes are in BP Amoco's Block 18 where the Platina and Plutonio discoveries were announced in

July of this year. These two successes are encouraging, as both wells lie close to the southern edge of the Congo Fan depocentre previously defined by Reynaud *et al.* (1998) in a region where source maturity could be a risk. Elf continue to regularly announce Block 17 successes, the latest may be the Cravo-1 well.

The Kuito discovery in Block 14 and the Girassol discovery in Block 17 are being developed. A 4th Quarter 1999 start-up for Kuito is envisaged. First production is scheduled for 2001 at Girassol. Construction invitations for the Belize and Benguela discoveries in Block 14 are expected later this year. In Block 17. Dalia has been declared commercial and a 2003 start-up is possible. Exxon are preparing their Kizombo development in Block 15.

Two of the most important of the previously mentioned exceptional factors are:

1) the presence of 20 by 20 kilometre structures in Block 17 that happen to be cut by numerous submarine channel sands (Rabier, 1999) and
2) the unexpected higher percentages of sand in the smaller structures of Block 14. This must also be the case in Block 15.

Little has been released concerning Shell's unsuccessful exploration programme in Block 16. This block is located in the depocentre of the Congo Fan and it appears, on the basis of the abstracts provided for the AAPG's 1998 meeting in Rio de Janeiro, that the younger Cretaceous (Iabe) source section has been largely stripped by the severity of the ensuing extensional tectonics. It is also likely that the oil prone horizons elsewhere in the younger Tertiary (Malembo) are replaced by depocentre focused, gas prone sources. The Block 16 results illustrate that even in the most prolific basins success need not be fairly proportioned. The block was released in June 1999.

Examination of Figure 4 in terms of the distribution of the new discoveries and the location of Block 16 suggests that the active oil window passes through the Regime 2 setting of Blocks 31, 32 and 33. It would also be reasonable to predict from the shape of the Congo Fan depocentre that the active oil window extends southwards into Block 34 and northwards into the yet to be tested deepwater blocks of Congo Brazzaville. These are Exxon's Mer Profonde Nord Block, Agip's Mer Tres Profonde Nord Block and Elf's Mer Profonde Sud and Mer Tres Profonde Sud Blocks. Multiple objectives are reported from this region by Hueper (1999). Considerable encouragement has already been provided by Elf's results from their still deepwater, Haute Mer Block that straddles the north-west prolongation of the Angola Block 14 discovery trend. Little detail has been released from Haute Mer, but it appears that some 500 MMbo of reserves may have already been identified. These are hosted in "feather-edge" young Tertiary sands and, at the Moho discovery, in "classic" play Albian sandstone and carbonates. Once again for the record, the first deepwater well, Sangha-1A, in this segment of the Congo Fan was drilled by the Seagap Group in 1978.

The initial success rates and the position and size of the active fairway strongly suggest that Congo Fan reserves will, with no more repetitions of Block 16-type gremlins, rise substantially above their present 7000 – 8000 MMbo base level. Indeed BP Amoco (Mayson, 1999) have suggested that the final reserves will be in the 15,000 to 20,000 MMbo range. Given their knowledge of the area, we conclude that the yet-to-be drilled Block 31-34 region merited last year's "feeding frenzy". Much will depend on source rocks maturity in the west and whether the right combinations of structural size and sand volumes required to support deepwater economics are present. The drilling in mid-1999 of two apparently dry holes in western Block 14 suggests that the fairway is more complicated than was hoped for.

The Moho discovery (400 MMbo reserves, 800 metre water depths) in Congo Brazzaville represents the furthest west pursuit so far of the increasingly important Atlantic Hinge controlled, Albian play in Congo Brazzaville and Angola (Cabinda). Total reserves for this play are approaching the 2500 MMbo level. Two Albian reservoired fields in this area, Elf's N'Kossa Field (Mer Profond) and Agip's Kitina Field (Marin VII) are in water depths between 200 and 500 metres. Vernet *et al.* (1996) provide an excellent account of the setting of this play, both in terms of the facies and the its relationship to the Atlantic Hinge. The probable extension of both the young Tertiary and the Albian fairways into Vanco's two blocks in southernmost Gabon is examined in the Gabon profile.

The Kwanza Fan

Drilling in the Blocks 19, 21 and 22 region of the Kwanza Basin is expected to begin in 2000. The existing shelfal and onshore wells proved excellent quality sands. The main risk will be the maturity of the drift succession. However, mature Tertiary oil-prone source rocks are present onshore (Burwood, 1999). Also, there are older, rift phase source rocks, many of which are mature and some of which can be of excellent quality (Henry *et al.*, 1995). Novel, late syn-rift, sag basin phase, source rocks may also be present (Henry and Abreu, 1998). Finally there are a number of "classic" play targets. It is too early to reliably comment on the reserve potential of this area.

The Benguela fans

Very little has been published concerning the Benguela region (Blocks 24 and 25 plus the far west of Texaco's Block 9). Brock *et al.* (1998) describe salt tectonics and note that seabed seeps are present – these samples were collected in 1996 by TDI-Brooks International. Given the abundance of sand delivered offshore, the reported indications of sands on seismic and the existence of AVOs (Brock *et al.*, 1998), this region looks exciting. However, the maturity of the sampled oils is low. Nevertheless this area has the right feel to it and significant discoveries are possible. The first well could be spudded in 2000.

Future opportunities

The immediate future is likely to see active interest in the unlicensed thickest sections of the Congo Fan. These are located to the west of Blocks 31, 32 and to a lesser extent 33, and are dominated by Structural Regime 3 settings. Interest will also develop in the strip of yet to be designated blocks west of 19 to 26 subject to the thickness of the drift section and/or the size of the potential targets. This region is predominately underlain by continental crust and will host salt induced structures. Elliott (1999) provides an indication of the structural potential. The northern area is known as the Ultra-deepwater Congo and the southern area is termed the Ultra-deepwater Kwanza. These two areas, plus the next strip of future blocks to the south, the Ultra-deepwater Namibe, are included on Figure 4 (only the northern end of the area is shown on Figure 4). Block 23, who is crossed by a line of young volcanic eruption centres, remains open.

No sheet sands of the type present in the Campos Basin giants have been described from the present deepwater blocks because the energy and/or gradient of the Congo submarine distributory system permitted channelling out to greater water depths than so far licensed. These sands because of their improved, Marlim-type geometries will be actively searched for. They will be present.

Interest is expected to develop in Moçamedes Basin area Blocks 26 to 30 since quality, oil-prone source rocks continue south of Block 25 into Namibia (Bray and Lawrence, 1999) and significant fluvial and, in the far south, aeolian derived sands should be present. Blocks 26 and 30 are likely to be the most sought after areas. Much will depend on the size of the targets and maturity considerations. Only the northern part of this area is shown on Figure 4.

The Gabon profile

Two young depocentres are present in Gabon. The largest of these is located in the central region of the country and is associated with the younger Tertiary (Neogene) resurgence of the Ogooué River. The other is the previously mentioned northern portion of the Congo Fan that was acquired by Vanco in early 1997. These areas are schematically depicted on Figure 5.

The northern termination of the Congo Fan

Considerable publicity has been given to Vanco's two large blocks in southern Gabon, Astrid Marin and Anton Marin (van Dyke, 1998). Astrid Marin with water depths in the 2500 to 3000 metres range occupies the extreme north end of the Congo Fan. Angola deepwater play analogues are expected in this area. Anton Marin contains numerous, salt cored, Albian (Madiela) targets in water depths ranging between 1000 and 2500 plus metres. The intention for Anton will be to locate the so far elusive northern extension of the shelf edge trend that is age equivalent to the increasingly important Sendji and Pinda carbonates and sandstone plays of Congo Brazzaville and Cabinda. These will also be targets to the north-west in Elf's Spring 1999 awarded G-97 and H-97 Blocks. Water depths in this pair of blocks, which extend out across the COB are in excess of 2500 metres. It is too early to predict reserves, but if maturity is present, field sizes could be of the same order as those present in Congo Brazzaville and Angola (Cabinda). Thus, discoveries in excess of 200 MMbo could reasonably be expected. Drilling in Vanco's blocks could begin in late 2000.

The Ogooué Fan

Four of Elf's shallow water fields have production from Tertiary channel sands related to the Ogooué River. Two of these fields, Pointe Clairette and N'Tchengue, were found in the late 1950s at the earliest stage of Gabon's exploration programme. Given the rate of progradation by the Ogooué in the younger Tertiary and the amount of sand supplied by the present river, substantial sand bodies are expected to be present in the deepwater blocks, notably those to the west of the producing region. Altogether twelve deepwater wells have been drilled in Gabon, eight of which were in water depths greater than 500 metres. Two of the deepwater wells were drilled by Shell in 1974 and 1975. Though there were initial suggestions of success in the new award areas, we suspect that new exploration models may now be needed. Elf relinquished their Falaba Block in April 1999. Their Sika shelf-edge block immediately to the east may have been released at the same time. More recently, Marathon has relinquished the next block to the north, Akoumba Marin.

Late Cretaceous to earliest Tertiary deepwater sand plays are also present in all these blocks. The main risk will be the maturity of the marine section above the salt. There could also be source quality issues. Elf's Akori Block straddles the COB as do Arco's Otiti Marin and Tolo Blocks. Salt tectonics will be present to the east of the COB.

The M-97 deepwater permit, which was awarded in the Spring of 1999 to Total, lies immediately to the north of this area. Plays will be similar to those to the south, though the Tertiary succession is likely to be less thick given the block's distance from the Ogooué River depocentre. The western portion of M-97 crosses the COB.

Too little information is available to predict reserves. We remain hopeful that they will eventually prove to be significant. A ninth licensing round is to open shortly. Deepwater acreage is expected to be included.

The Equatorial Guinea (Rio Muni) to Cameroon profile

The first deepwater well in this segment of West Africa, Triton's M'Bini-1 in Block G, may prove to be yet another turning point discovery. An upside of 500 MMbo has already been suggested. 20,000 BOPD flow rates are possible. The find has been named La Ceiba. It is featured on Figure 6. Loader *et al.* (1998) succinctly presented the pre-well excitement by demonstrating that deepwater Rio Muni is associated with up to 6000 metres of post-rift section, early Albian aged source rocks, late Cretaceous (Senonian) and Tertiary sand channels, AVO anomalies and structuring. Bray and Lawrence (1999) model Cenomanian and Turonian maturity. As shown on Figure 6 La Ceiba is located immediately to the west of the Atlantic Hinge. All the previous Rio Muni wells are located to the east either on the Hinge or further inboard towards the coastline (these are not included on Figure 6). The general setting of La Ceiba equates to the right central region of the seismic line portion of Figure 11 in Myers *et al.* (1996).

The La Ceiba discovery is an excellent example of why the West African deepwater is so important. It also vividly demonstrates the role of the Atlantic Hinge in creating deepwater plays by bringing in mature source rocks and sands opposite previously disappointing shelf settings. It is premature to predict deepwater reserves in this region, but we are optimistic that they will prove to be considerable, possibly in the 2000 MMbo plus category. La Ceiba will spur interest along the entire deepwater margin from northernmost Gabon to the Douala Sub-basin of Cameroon. The section as can be seen from the seismic lines provided by Myers *et al.* (1996) is thick enough (4-5 seconds TWT) for maturity in the late Cretaceous and older source section. Traps away from the transcurrent fault cuts will be mainly stratigraphic. The main risk west of the COB is the robustness of the migration pathways between the kitchens and the reservoirs – detailed examination of the seismic lines included in Myers *et al.* (1996) suggests that there is sufficient differential subsidence disturbance to permit migration. "Pop-up" structures related to young strike-slip faults have been illustrated at promotional meetings.

The Equatorial Guinea bid round closed on August 2nd this year with reports of interest (doubtless these bids will now be in the process of active review). The Cameroon deepwater round closes on 31 March 2000. The Cameroon open acreage is located to the south-west of the Atlantic Hinge (the producing Kribi Field is located on this hinge line). Water depths are in the range 500 to 1900 metres. As with Rio Muni, there are both Cretaceous and Tertiary sand objectives. Meeting presented modelling indicates that the marine Cretaceous source section is mature.

The Nigeria/Cameroon (Rio del Ray)/Equatorial Guinea/São Tome profile

Initial West African expectations were highest for the Nigeria region because of the size and abundance of the onshore fields and the amounts of sand known to have been delivered to the deepwater. Regrettably the initial deepwater wells in Nigeria were disappointing and apart from Shell's Bonga Field (the reserves may be greater than 1000 MMbo) the first three years of drilling up to late-1998 yielded no major discoveries. Indeed, the results were deemed sufficiently discouraging for Mobil to relinquish a few months ago their OPL 221 permit despite the presence of the Adaka discovery well. Statoil have given up their interest in OPL 210 and BP Amoco has pulled out of Nigeria altogether.

In the last year, following Texaco's Agbami (OPL 216) discovery in late-1998, the success rate has significantly improved. Agbami reserves, following the initial indications from the second well, could be substantially in excess of 1000 MMbo. The structure is reported to be a large four-way dip closed anticline. Statoil's N'nwa in (OPL 218) may hold 500 MMbo and the other larger discoveries (Erha (OPL 209) and Ukot (OPL 222)) could have reserves in excess of 500 MMbo between them. In total, reserves, inclusive of all the smaller discoveries and the Zafiro area discoveries in Equatorial Guinea, appear be of the order of 4000 MMbo. Development plans for Bonga have been recently announced. First oil is planned for late 2000/early 2001. Texaco are actively considering development plans their Agbami find. A talk on Zafiro is scheduled for this meeting.

Given the excellent stacking of the play ingredients, we are puzzled by the seemingly low magnitude of the cumulative reserves. Possibly, given the energy of the system, the best sands lie within the toe thrust region and beyond (Figure 7). It may be significant here that the new larger discoveries, together with Bonga, are positioned in 1000 metres or more of water. A similar relationship between field size, sand quality and greater water depths exists in the Gulf of Mexico. The quality of the source rocks is expected to improve oceanwards as the Cretaceous section re-enters the oil window (Cameron *et al*, 1999). Less gas prone kerogens are likely on the Tertiary source succession. We believe that deepwater Nigeria region could catch up Angola and become, as initially predicted, a second centre of deepwater production in West Africa. A key target will be toe thrust structures (Morgan, 1999). Much will depend on maturity issues and the charging potential for the fan sands within the little structured section beyond the toe thrust belt. The first well that will begin to test our predictions, Akpe-1, is planned to be spud in OPL 246 this November. A deepwater round is likely in 2000. Mobil's TEA in eastern and northern São Tome waters expires in March 2000.

There is, as is evident from the track of the Atlantic Hinge (Figure 7), deepwater Cretaceous sand potential in OPLs 312 to 314. This potential will continue westwards into Benin, Togo and beyond. Though source rocks are present, maturity will be a major risk factor. Togo's bid round closes on 1 November 1999. It includes deepwater acreage that hosts a wide range of opportunities. These range from 4-way dip closures to base of slope and canyon fill targets.

The Ghana to Ivory Coast profile

The first deepwater well in this region was drilled in 1978/79 by Phillips in Ghana. The second deepwater well, East Grand lahou-1, has just been completed by Ocean Energy and Shell in Ivory Coast block CI-105. Regrettably it was P&A'd as a dry hole. 3-D seismic was shot earlier this year for Hunt in Ghana's South Cape Three Points Block immediately to the east of the Ivory Coast border. A well, WCTP-2, is planned for early December in 1100 metres of water.

The deepwater targets in both countries are, as in Liberia to the west, older Cretaceous fault blocks and little structured, younger Cretaceous and Tertiary fans. Both are positioned oceanwards of the existing fields and developments, all of which are hosted by the Atlantic Hinge (Figure 8 and Morrison *et al.*, 1999). The fault blocks are related to both residual and younger "pop-up" tectonics associated with the Romanche Transform Fault.

Mature Aptian and Albian aged source rocks are present. Excellent quality, younger Cretaceous sources (Wagner and Pletsch, 1999) are present, but their maturity is uncertain. Significant sand can be expected given the size of the rivers draining to the coast, for example the Volta River in Ghana. Albian to Cenomanian aged reservoirs are the fault block objectives. Risks once again are maturation related. In some settings there will be fault and unconformity access from the source-bearing Albian section into the cover succession fans. Reservoir quality is an unknown in the fault block target structures.

It is too early to predict reserves. We would not be surprised to see cumulative reserves in excess of 1000 MMbo booked within the next five years. Ranger operate two deepwater blocks, CI-101 and CI-103. These are located in the east of the country. Vanco acquired two deepwater blocks in the Ivory Coast, CI-109 and CI-112, earlier this year. They are located in the west of the country and both may cross the COB. Three deepwater blocks remain open in the Ivory Coast. Minimal deepwater acreage remains open in Ghana.

Conclusions and final comments

In excess of 12,000 MMb of deepwater oil has been discovered in West Africa since deepwater exploration began in Angola in 1994. This figure is already equates to the Brazilian total of 13,000 MMbo (this sum includes the just announced giant discovery in the previously problematic Santos Basin).

The West African deepwater will continue to be a long-term focus for the oil industry. Indeed we consider it likely that the focus will sharpen as globally significant discoveries continue and successes elsewhere decline. Further Angola Block 31-33 "feeding frenzies" will erupt as new opportunities and technologies emerge.

Angola will continue to host for the immediate future the largest reserves, but we predict that the Niger Delta region will ultimately catch up and could possibly surpass Angola, particularly if the Kwanza region of Angola proves to be disappointing.

We anticipate further La Ceiba-type successes as exploration extends further into virgin regions west of the Atlantic Hinge. We predict that the best results will continue to be achieved with young Tertiary targets. Late Cretaceous (Senonian) deepwater sands related to those first discovered more than thirty years go in the Ogooué Fan of Gabon will also be found. Cretaceous reservoired giants equivalent to Roncador (2000 MMbo plus) in the Campos Basin of Brazil cannot be discounted given the regional nature of the late Cretaceous drainage changes within Africa. It is too early to comment reliably on the future for the "classic" plays in deepwater settings: one dry hole in the Ivory Coast does not mean that they can be discounted. We are confident that the sediment thicks above ocean crust host oil, but the combination of great water depths and the general absence of conventional structures suggest that these areas will not see earlier drilling initiatives. However, as the supply of conventional targets diminishes globally, it will not be many years before international symposia address their exploitation.

We are unable to include ultimate reserves due to the lack of sufficient public domain information on sediment thicknesses and heat flow. However, we will attempt a summary during the presentation. Source maturity is the greatest risk. Migration pathways are another significant risk factor. Reservoir, seals and trap issues are not expected to be major risks. Source rocks are invariably present.

This is our first compilation for IBC on this topic. We have been too sweeping in some of our observations and we may have inadvertently, in the process, overlooked important public domain information. We hope that errors and omissions will be pointed out to us so that the quality and the value to industry of this product can be improved.

We do not have a complete set of turning points for the depicted block boundaries or for the international borders, even where they have been determined. Many of the depicted geological boundaries are necessarily schematic. We have found variances in our water depths compared to other publications. Please be aware of these limitations when using the maps and contact us should you have any queries on their reliability.

References

Bray R. and S. Lawrence Bray R. and S. Lawrence, 1999. Nearby finds brighten outlook for Equatorial Guinea and Namibia. Oil and Gas Journal, 97, 5, p. 67-69 and 72-75.

Brink A.H, 1974. Petroleum geology of Gabon Basin. Bulletin of the American Association of Petroleum Geologists, 58, 2, p. 216-235.

Brock D., L. Smith and R. Sarg, 1998. Sequence stratigraphic prediction of reservoir and source, deep-water Angola Block 24. 1998 American Association of Petroleum Geologists International Conference and Exhibition, November 8-11 1998, Rio de Janeiro, Extended Abstracts Volume, p. 842.

Burke K., 1996. The African Plate. South African Journal of Geology, 99, 4, p. 341-410.

Burwood R., 1999. Angola: source rock control for Lower Congo coastal and Kwanza Basin petroleum systems. *In*: The Oil and Gas Habitats of the South Atlantic, Cameron N.R., R.H. Bate, and V.S. Clure (editors), Special Publication of the Geological Society No. 153, p. 181-194.

Cainelli C. and W.U. Mohriak, 1999. General evolution of the eastern Brazilian continental margin. The Leading Edge, July, p. 800, 802-804 and 861.

Cameron N.R., C.F. Schiefelbein, J.M. Brooks and M.G.P. Brandão, 1998. The application of seabed sampling and organic geochemistry to frontier basin exploration in Angola. 3rd Annual Forum Worldwide Deepwater Technologies, London, 17-18 February 1998, pp. 8.

Cameron N.R., Brooks J.M. and J.E. Zumberge, 1999. Deepwater Petroleum Systems in Nigeria: their identification and characterisation ahead of the drill bit using SGE technology. IBC Nigeria Energy Summit, London, 15-16 June 1999, pp. 20.

Cameron N.R., R.H. Bate, V.S. Clure and J. Benton, 1999. Oil and Gas Habitats of the South Atlantic: Introduction. *In*: The Oil and Gas Habitats of the South Atlantic, Cameron N.R., R.H. Bate, and V.S. Clure (editors), Special Publication of the Geological Society No. 153, p. 1-9.

Cohen H.A and K. McClay, 1996. Sedimentation and shale tectonism of the southwestern Niger Delta front. Marine and Petroleum Geology, 13, 3, p. 313-329.

Cornford C., C. Burgess and R. Kelly, 1999. Modelling the deep water West Atlantic margin - transitional crust, transform margins and transient heat flow. Bulletin of the American Association of Petroleum Geologists, 73, 8, p. 1307 (abstract).

Dale C.T., C.R. Lopes and S. Abilio, 1990. Takula Oil Field and the Greater Takula Area, Cabinda, Angola. American Association of Petroleum Geologists Memoir No. 54, p. 197- 215.

Doust H. and E. Omatsola, 1990. Niger Delta. American Association of Petroleum Geologists Memoir 48, p. 201-238.

van Dyke G., 1998. Exploring the deepwater offshore Gabon. 3rd Annual Forum Worldwide Deepwater Technologies, London, 17-18 February 1998, pp. 33.

Elliott P. 1999. Hydrocarbon prospectivity and salt tectonics offshore Angola. IBC Angola Energy Summit, 2-3 March 1999, pp. 24.

Henry S.G., W.D. Brumbaugh and N.R. Cameron, 1995. Pre-salt source rock development on Brazil's conjugate margin: West African examples. 1st Latin American Geophysical Conference, Rio de Janeiro, August, extended abstract, pp.3.

Hueper P.F., 1999. Offshore West Africa. Petroleum Economist, June, p. 56-64.

Henry S.G. and V. Abreu, 1998. Marine transgressions in the Pre-salt of the South Atlantic: new models for rifting and continental breakup. American Association of Petroleum Geologists Annual Convention, Salt Lake City, extended abstract, pp. 3.

Jackson M.P.A., C. Cramez and W.U. Mohriak, 1998. Salt-tectonics provinces across the continental-ocean boundary in the Lower Congo and Campos Basins of the South Atlantic. 1998 American Association of Petroleum Geologists International Conference and Exhibition, November 8-11 1998, Rio de Janeiro, Extended Abstracts Volume, p. 40-41.

Karner G.D., N.W. Driscoll, J.P. McGinnis, Brumbaugh W.D. and N.R. Cameron, 1997. Tectonic significance of syn-rift sediment packages across the Congo-Cabinda continental margin. Marine and Petroleum Geology 14, 7, p. 973-1000.

Kean A.E., 1999. Multidisciplinary, crossfunctional geophysical integration in the Campos Basin. The Leading Edge, July, p. 806-811.

Knight R. and J. Westwood, 1999. Long-term prospects very bright for deep waters off West Africa. Oil and Gas Journal, 97, 3, p. 33-3 and 38.

Lauferts H., 1998. Deep offshore West Niger Delta slope, Nigeria - scale and geometries in seismic and outcrop indicating mechanisms for deposition. Extended Abstracts Volume. 1998 AAPG International Conference and Exhibition, November 8-11, 1998 Rio de Janeiro, p. 18-19.

Loader P.R., K.Goh, M.K. Taylor and P. Dailly, 1998. Tectonostratigraphy of the Rio Muni Basin, Equatorial Guinea: implications for future exploration potential. 1998 AAPG International Conference and Exhibition, November 8-11 1998, Rio de Janeiro, Extended Abstracts Volume, p. 592-593.

Lundin E. R., 1992. Thin skinned extensional tectonics on a salt detachment, northern Kwanza Basin, Angola. Marine and Petroleum Geology, 9, 4, p. 405-411.

McHargue T.R.,1991. Stratigraphic development of proto-South Atlantic rifting in Cabinda, Angola: a petroliferous lake basin. American Association of Petroleum Geologists Memoir 50, p. 307-326.

Mayson H.J., 1999. BP Amoco in Angola. IBC Angola Energy Summit, 2-3 March 1999, pp. 15.

Meyers J.B. and Rosendahl, 1991. Seismic reflection character of the Cameroon volcanic lines: evidence of uplifted oceanic crust. Geology, 10, 11, p. 1072-1075.

Meyers J.B., B.R. Rosendahl, H. Groschel-Becker. J.A. Austin Jr. and P. A. Rona, 1996. Deep penetrating MCS imaging of the rift-to-drift transition, offshore Douala and North Gabon basins, West Africa. Marine and Petroleum Geology, 13, 7, p. 791-835.

Morgan R., 1999. Ultra-deepwater prospectivity in the Niger Delta. IBC Nigeria Energy Summit, London, 15-16 June 1999, pp. 8 plus 7.

Morrison J., J. Tea, B. N'Zalasse and V. Boblai, 1999. A sequence stratigraphic approach to exploration and re-development in the Abidjan margin, Côte d'Ivoire. Offshore West Africa, Abidjan, 22-23 March 1999, pp. 12.

Rabier G., 1999. Block 17 - assessment of the latest deepwater discovery and the development plan for Dalia and Rosa. IBC Angola Energy Summit, 2-3 March 1999, pp. 23.

Reynaud F., J. Amaral, D. Drapeau and D. Grauls, 1998. Post-Salt Petroleum Systems in the Lower Congo Basin (Congo-Angola). 1998 AAPG International Conference and

Exhibition, November 8-11 1998, Rio de Janeiro, Extended Abstracts Volume, p. 838-839.

Schiefelbein C.F., J.E. Zumberge, N.R. Cameron and S.W. Brown, 1999. Petroleum Systems in the South Atlantic Margins. *In*: Cameron N.R., R.H. Bate, and V.S. Clure (editors). The Oil and Gas Habitats of the South Atlantic. Special Publication of the Geological Society No. 153, p. 169-180.

Teisserene P. and J. Villemin, 1990. Sedimentary basin of Gabon - geology and oil system. American Association of Petroleum Geologists Memoir 48, p.117-199.

Wagner T. and T. Pletsch T., 1999. Tectono-sedimentary controls on Cretaceous black shale deposition along the opening of the Equatorial Atlantic Gateway (ODP Leg 159). *In*: The Oil and Gas Habitats of the South Atlantic, Cameron N.R., R.H. Bate, and V.S. Clure (editors), Special Publication of the Geological Society No. 153, p. 241-266.

Worrall D.M., B.E. Bradford and J. Straccia, 1999. Frontier deepwater basins: what's next? Bulletin of the American Association of Petroleum Geologists, 83, 8, p. 1346 (abstract).

Vernet R., C.A. Assoua-Wande, L. Massamba and P. Sorriaux, 1996. Paléogéographie du Crétacé (Albien-Maastrichtien) du Bassin Côtier Congolais. Elf Aquitaine Mémoire 16, 1996, p. 39-56.

Contacts

Nick Cameron is the UK representative for TDI-Brooks International, Inc. and GeoMark Research, Inc. Contact options include: +44-(0)1494-776850 (telephone/fax) and nick@topaz.primex.co.uk. Information relating to TDI-Brooks International reports and the company's future coring programmes may be obtained from either Dr. Jim Brooks [+1-409-695-3634 (telephone), +1-409-695-5168 (fax) or Drjmbrooks@aol.com] or Bob Hoff [+1-281-463-6493 (telephone), +1-281-463-6432 (fax) or Bobcassy@aol.com].

Ken White is a founding co-director of EIS Energy Information Services Ltd. whose responsibilities include the research and creation of the monthly International Explorer publication. He may be contacted by telephone (+44-(0)1737 772599), by fax (+44-(0)1737 773028) or by e-mail (eis@energyinfoservices.co.uk). The same contact details may be used for enquiries regarding the company's other publications (hard copy or electronic), maps and databases. The same numbers may be used for contacting Mr J. Hartley, Managing Director, for enquiries regarding the company's other publications (hard copy or electronic), maps and specific database research projects.

The figures and the talk graphics were prepared by Steve King (+44-(0)1442-825128 and steve@topaz.primex.co.uk).

Figures

Figure 1. Total discoveries by year for Angola, Congo Kinshasa, Congo Brazzaville and Gabon between 1960 and mid-1998 (modified from Cameron *et al.*, 1999). Key discovery dates and events are indicated.

Figure 2. The change in reserve distribution in Angola following the deepwater successes. Malongo Field in Cabinda is the type example of a Pre-Salt play. Pacassa, Lombo and Bomboco (Cabinda) Fields are type examples of the Mid-Cretaceous Platform plays. Takula Field in Cabinda is the best representative of the drowning phase.

Figure 3a. The deepwater framework from Angola to southern Gabon.

Figure 3b. The deepwater framework from central Gabon to the Ivory Coast.

Figure 4. The Angola and Congo Brazzaville deepwater play elements.

Figure 5. The Gabon deepwater play elements.

Figure 6. The Equatorial Guinea (Rio Muni) to Cameroon deepwater play elements.

Figure 7. The Nigeria deepwater play elements.

Figure 8. The Ghana to Ivory Coast deepwater play elements.

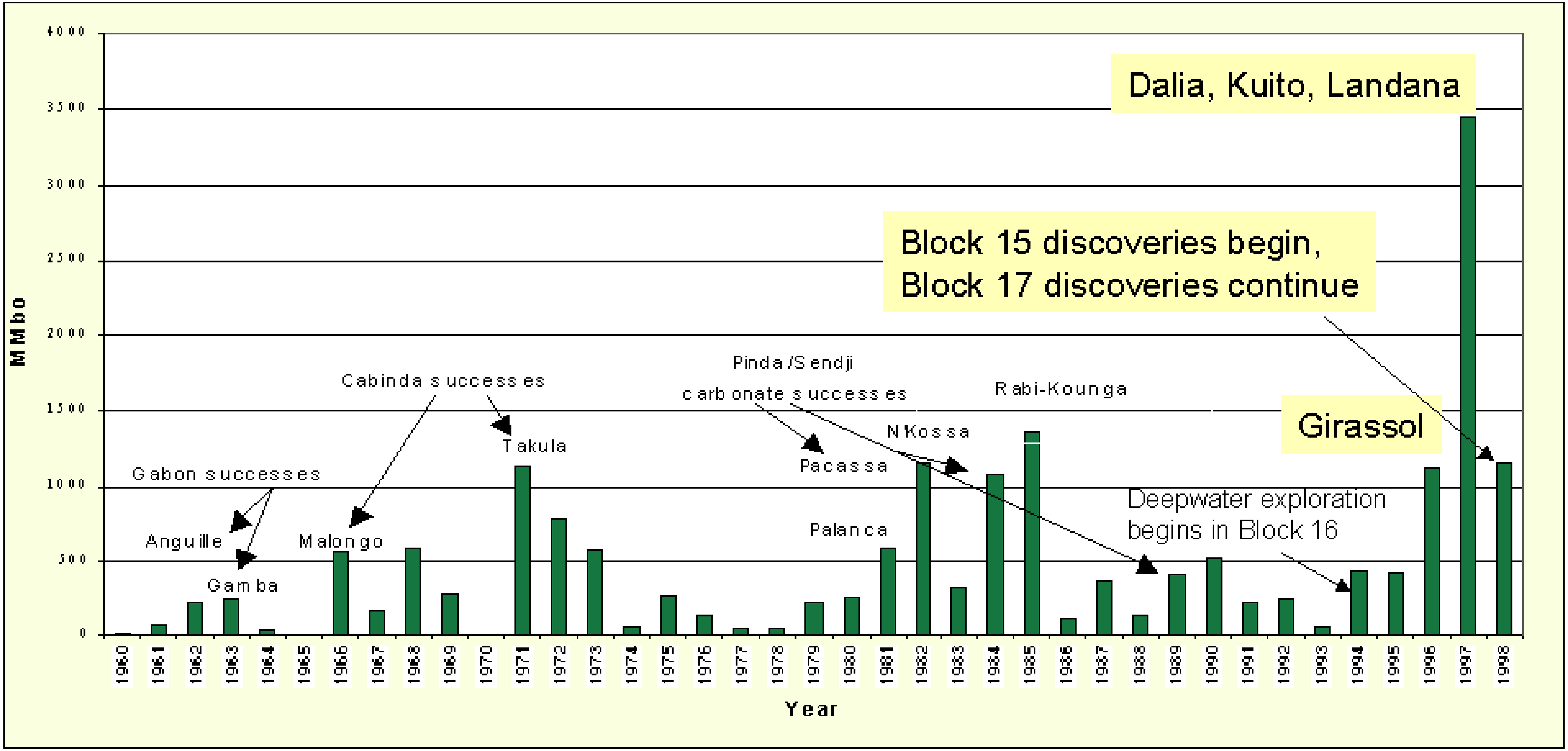

Figure 1. Total discoveries by year for Angola, Congo Kinshasa, Congo Brazzaville and Gabon between 1960 and mid-1998 (modified from Cameron *et al*., 1999). Key discovery dates and events are indicated.

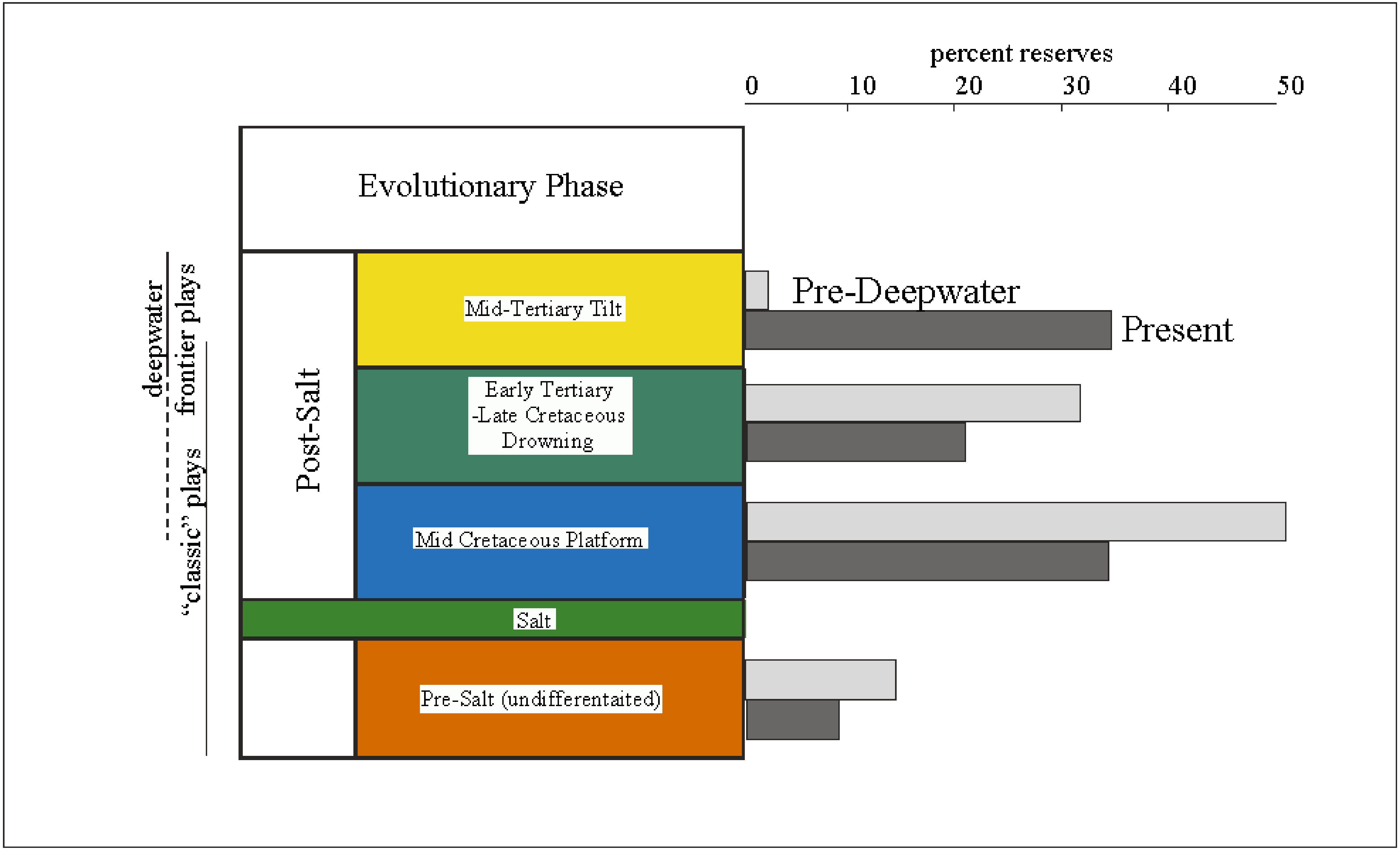

Figure 2. The change in reserve distribution in Angola following the deepwater successes. Malongo Field in Cabinda is the type example of a Pre-Salt play. Pacassa, Lombo and Bomboco (Cabinda) Fields are type examples of the Mid-Cretaceous Platform plays. Takula Field in Cabinda is the best representative of the drowning phase.

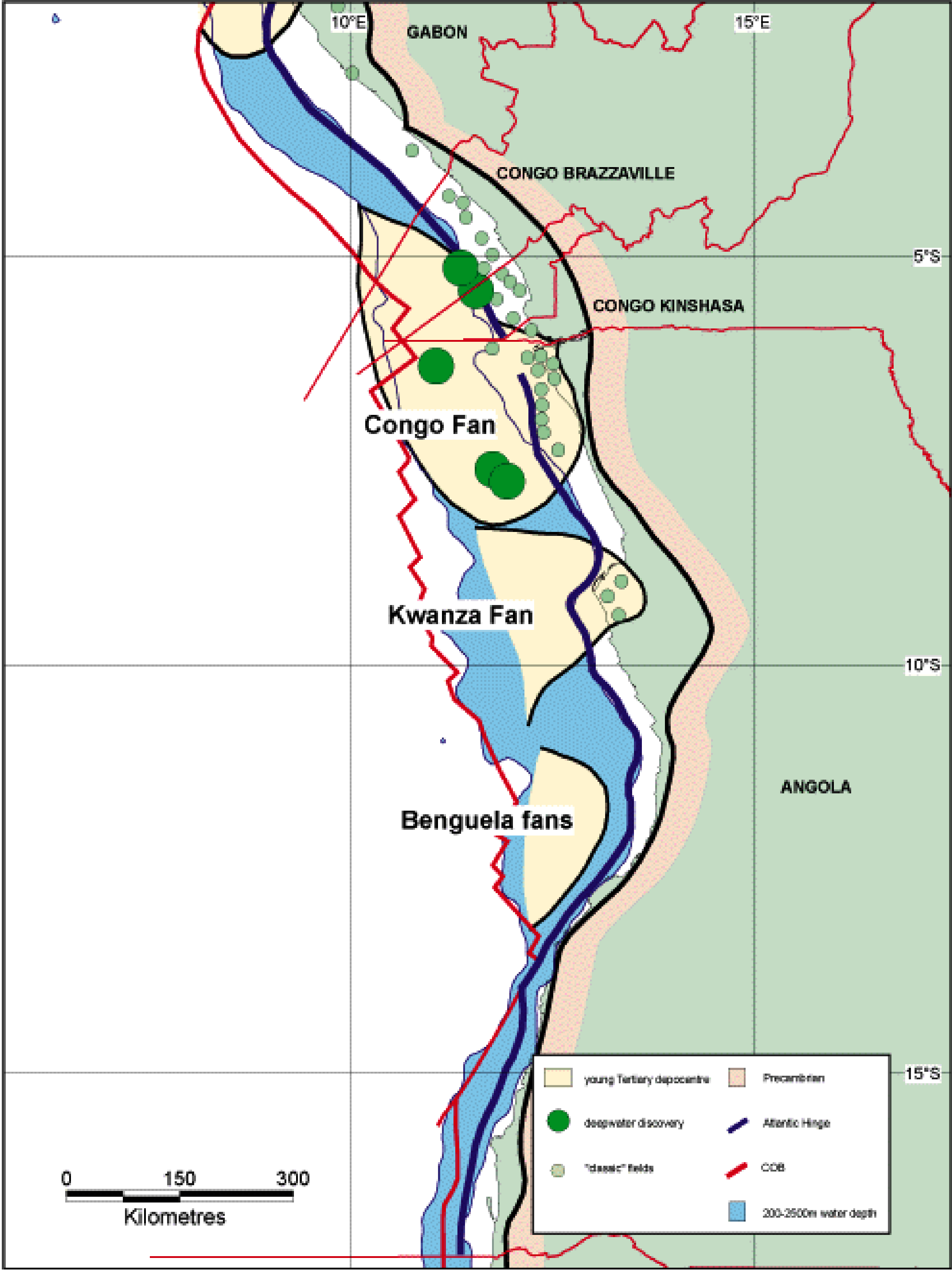

Figure 3A. The deepwater framework from Angola to Southern Gabon

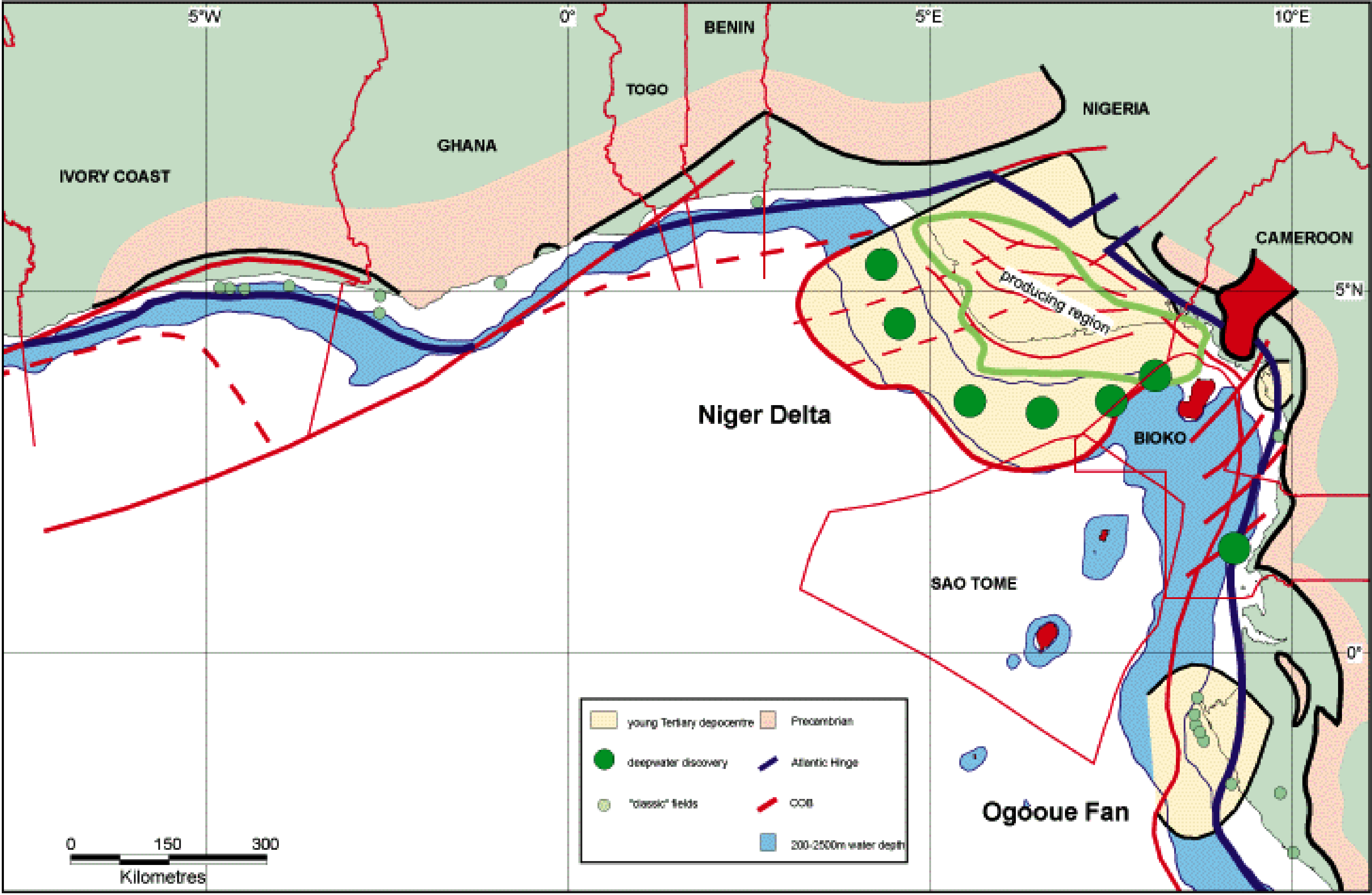

Figure 3B. The deepwater framework from central Gabon to the Ivory Coast

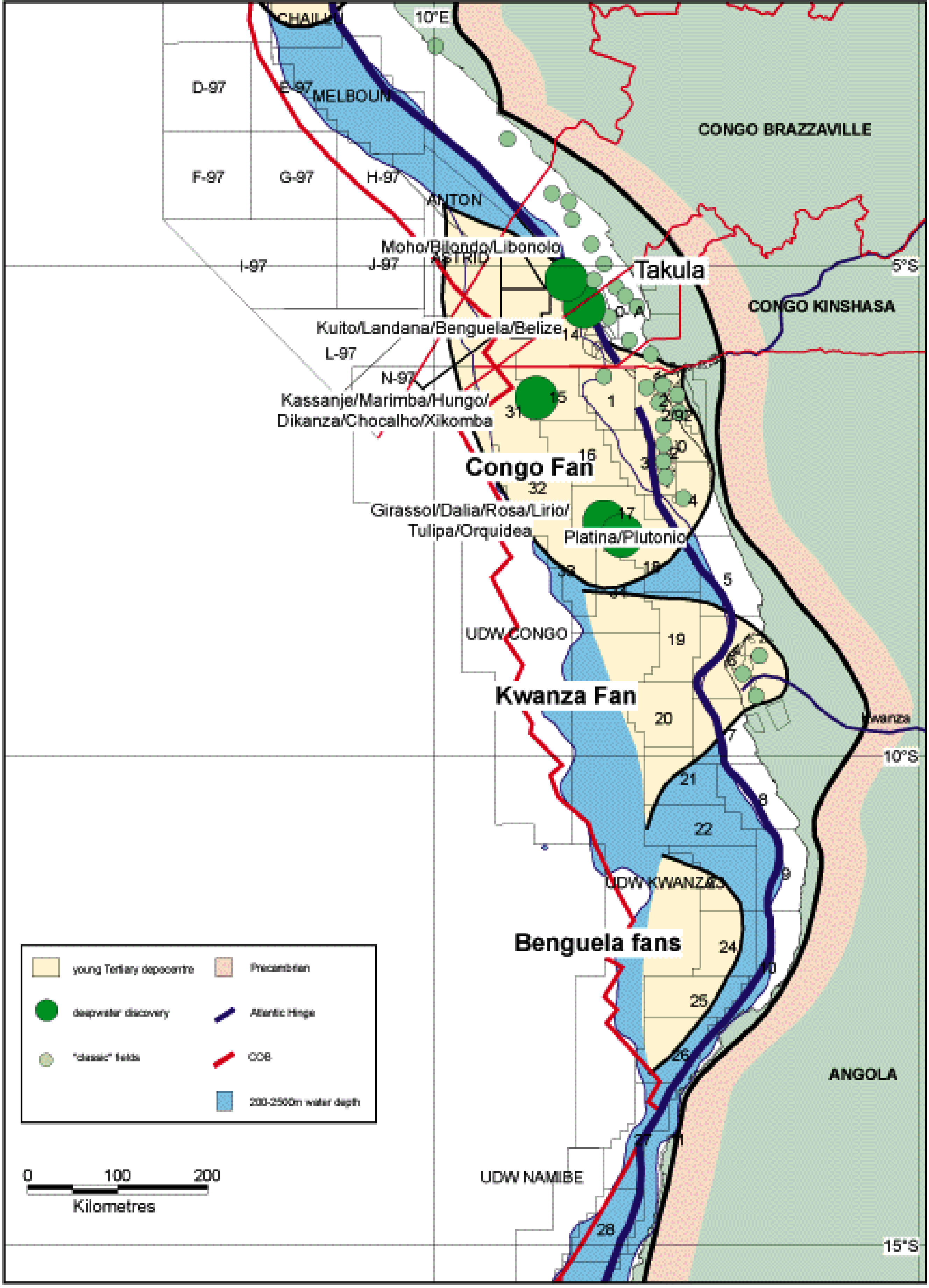

Figure 4. The Angola and Congo Brazzaville deepwater play elements

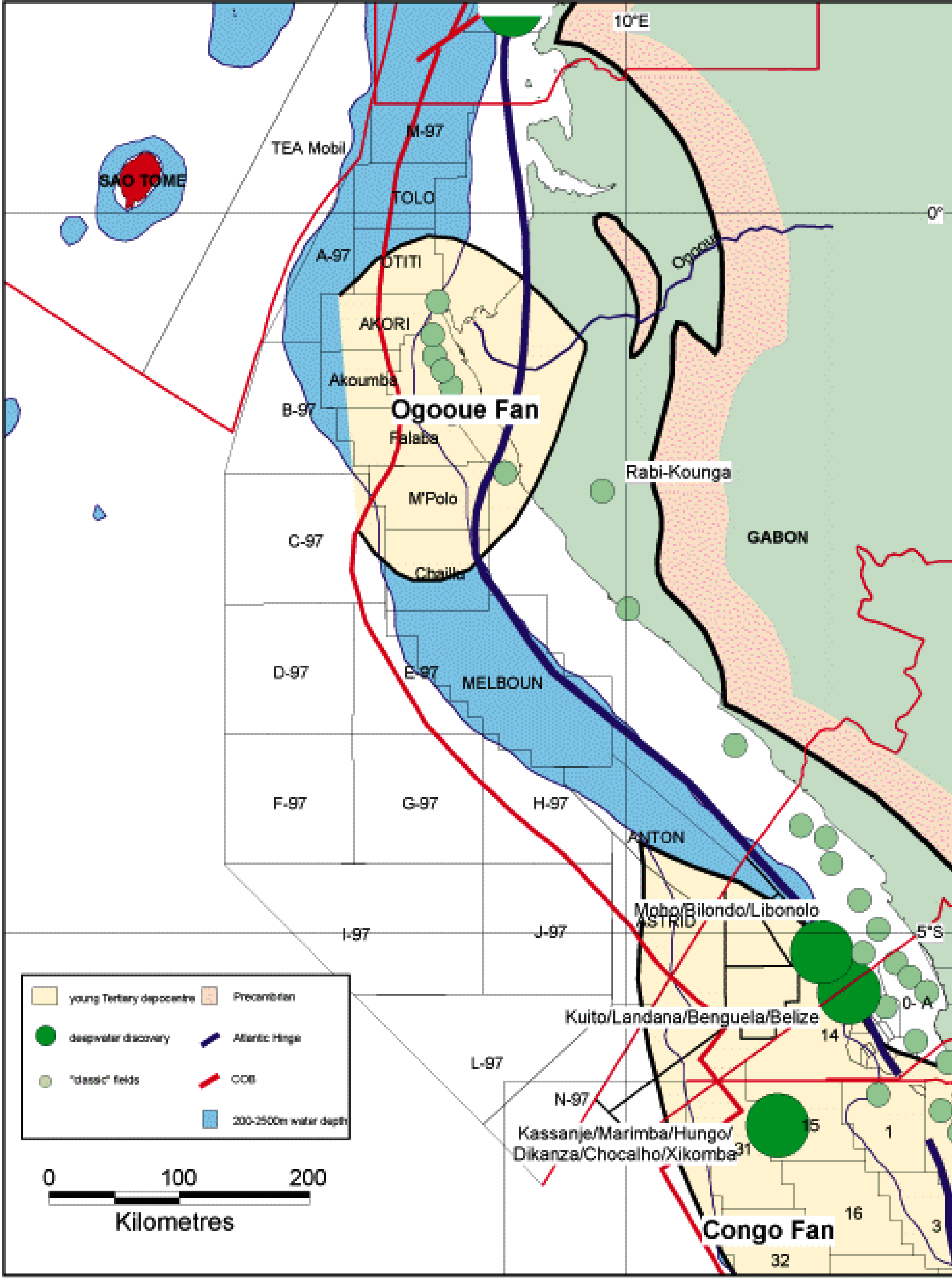

Figure 5. The Gabon deepwater play elements

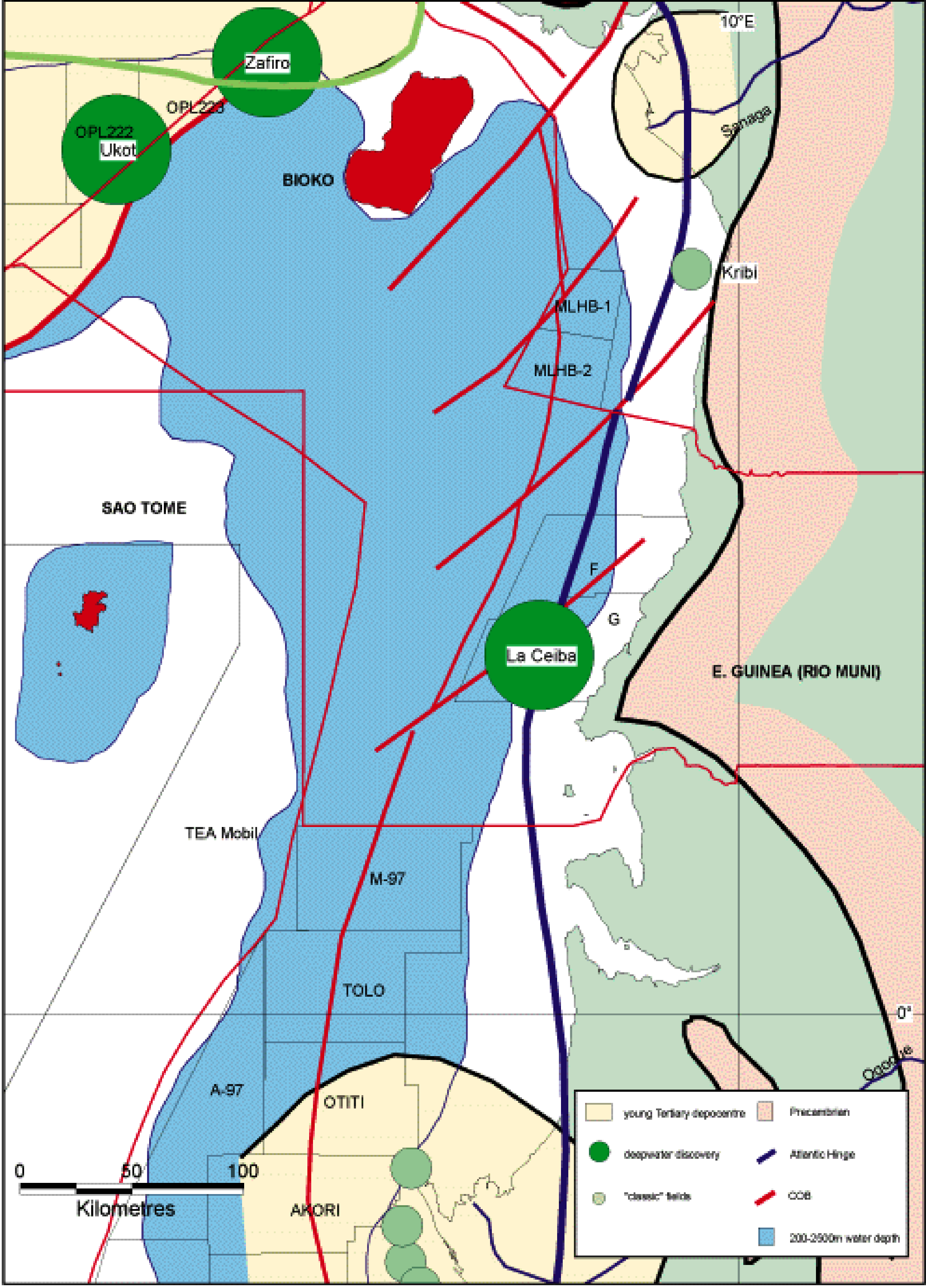

Figure 6. The Equatorial Guinea (Rio Muni) to Cameroon deepwater play elements

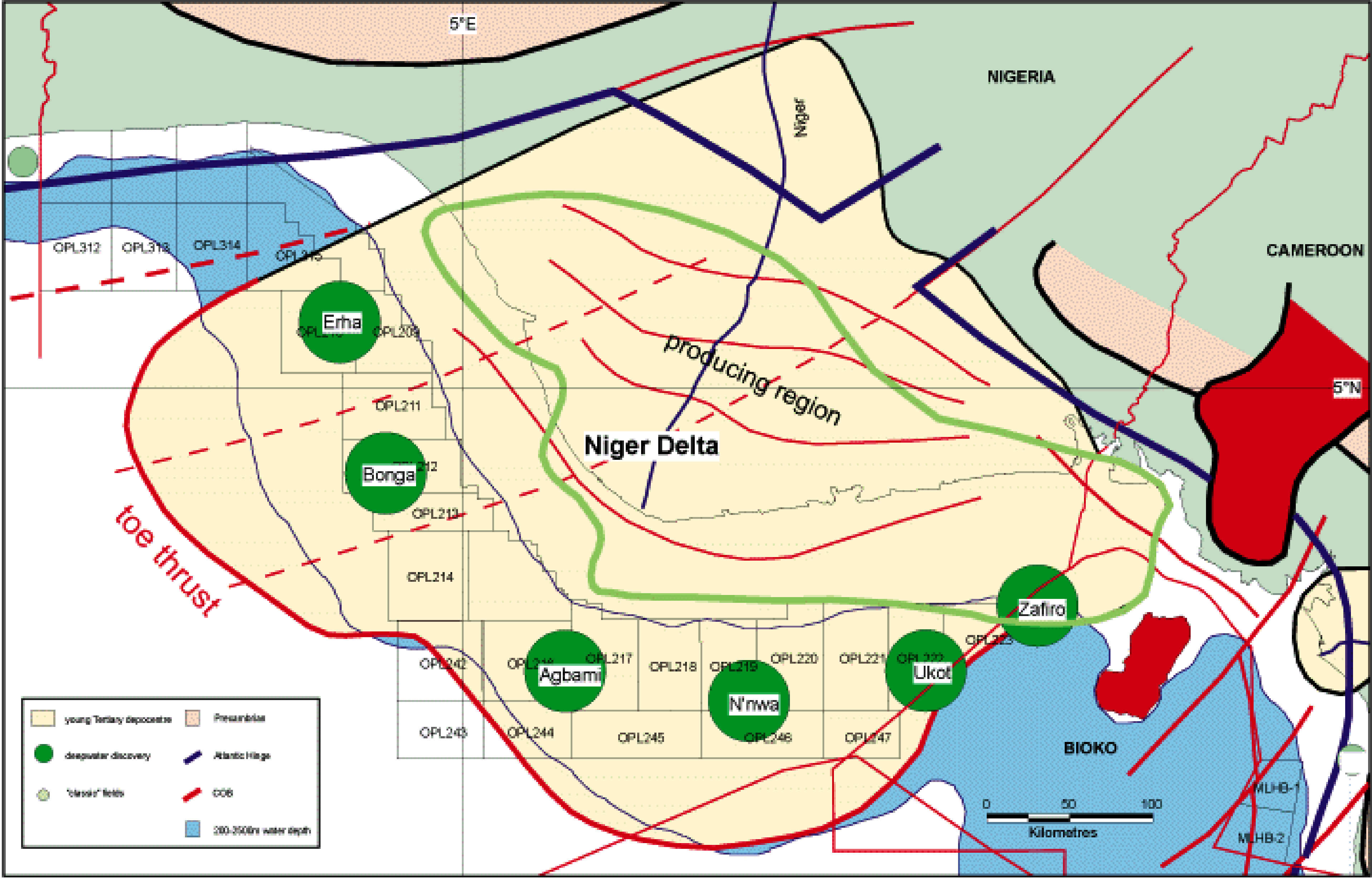

Figure 7. The Nigeria play elements

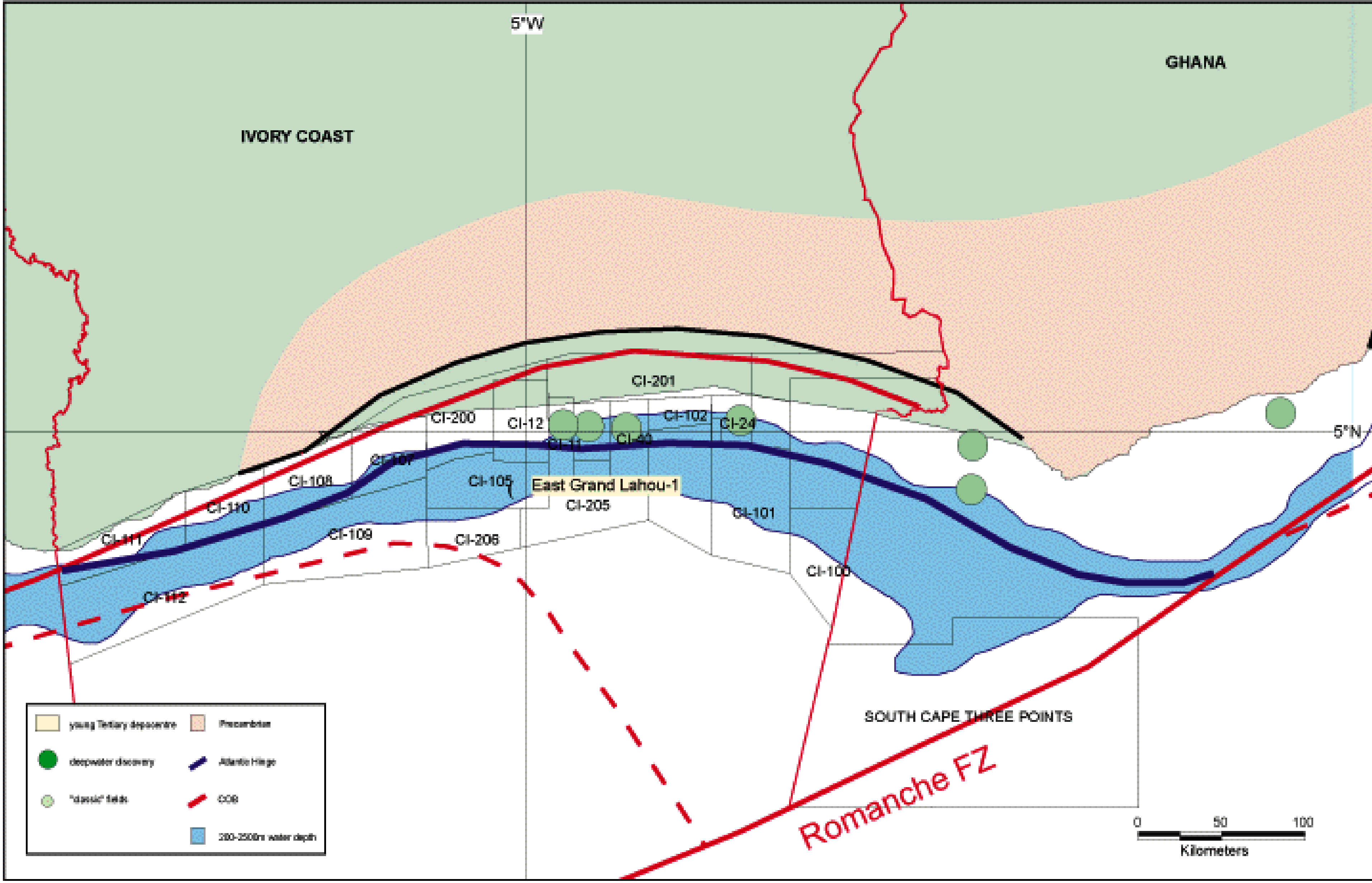

Figure 8. The Ghana to Ivory Coast deepwater play elements