SEDIMENTOLOGICAL ASPECTS OF OIL FIELDS IN THE NIGER DELTA

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SUMMARY

One of the most conspicuous geological features of the Niger Delta is its growth fault pattern. Almost all the oil reserves are contained in rollover structures which are associated with growth faults. These structural features are thought to have been formed by the force of gravity acting on a thick body of sediments supplied mainly by the Niger River. These sediments form a typical deltaic offlap sequence consisting of a wedge of continental sands grading downwards into marine clayey sediments which, at a greater depth, are in a state of undercompaction.

Stratigraphically most of the known oil accumulations occur in the paralic sequence, i.e. the transition zone between the continental and fully marine sediments. The paralic sequence consists of a large number of sedimentary offlap cycles, each cycle starting with a marine clay, generally less than 150 feet thick and changing upwards progressively into proximal fluviomarine interlaminated silt, sand and clay which are usually followed by various types of more sandy barrier-bar and coastal-plain deposits. The cycles are terminated by transgressions which erode away part of the offlap sequence and which are generally represented by a thin, very fossiliferous gravelly sand.

In this paper the relationship between sedimentation and growth faults is discussed. Examples are given of depositional cycles and of the associated types of reservoir rock. Attention is given to the influence of the depositional environment on the petrophysical properties of the rock, reservoir continuity and reservoir imhomogeneities.

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INTRODUCTION

The research for oil in Nigeria by the Shell-BP Petroleum Development Company started in 1937. Commercial oil production commenced in 1958 and by September 1970 about 1800 accumulations of oil and gas had been discovered in 146 structural features.

In addition numerous discoveries have been made by other companies, particularly in the offshore region. The position of 91 oil fields is shown in fig. 1. Further discoveries can be expected as exploration activities continue.

Even now the Niger Delta is a more prolific oil province per unit of surface area than the Gulf coast of Texas and Louisiana. Oil production from Shell-BP

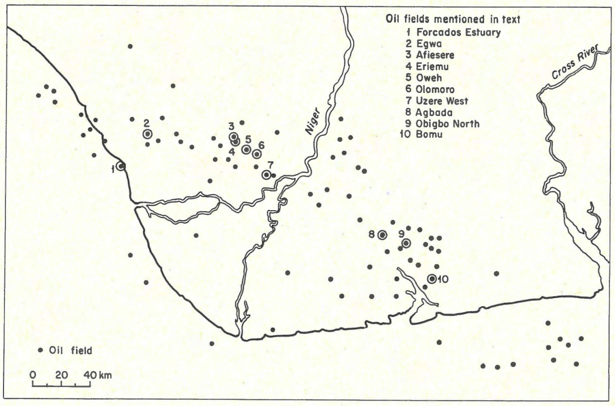

Fig. 1
Oil fields in Nigeria

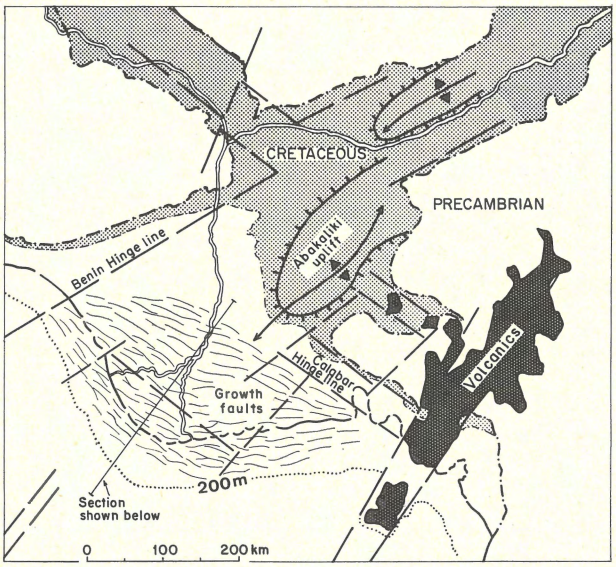

Fig. 2a.
Niger delta, megatectonic elements and growth fault area.

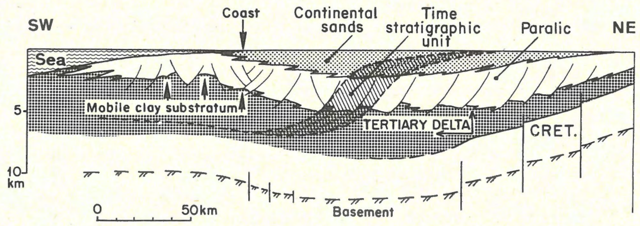

Fig. 2b.
Schematic section perpendicular to the coastline.

alone will be over one million barrels per day from some thirty fields by the end of 1970.

The stratigraphy of the Niger Delta, the major sedimentary cycles and tectonic movements of the basement are described by S h o r t and S t ä u b l e (1967), F r ä n k l and C o r d r y (1967) and M a r o n (1969). These subjects are summarized briefly, but this article deals mainly with growth faulting and the application of sedimentology to oil-field development. Comparisons of the Tertiary with the Recent Niger delta sediments are also made.

It is stressed that the ideas presented in this article represent the outcome of the combined efforts of many geologists over a twenty year period.

STRATIGRAPHY AND TECTONIC FRAME WORK

The Nigerian pericratonic basin was formed by rift faulting of the Pre-Cambrian (fig. 2a). The outlines of the delta are controlled by deep-seated faults, e.g. along the "Benin" and "Calabar" hinge lines. At least three major sedimentary cycles have been deposited in the basin since early Cretaceous times (M u r a t, 1970). The delta started growing during the second cycle between Campanian and Paleocene transgressions.

The third sedimentary cycle, commencing in the Paleocene, is responsible for the main part of the delta's growth. The deltaic sequence consists essentially of clayey marine sediments overlain by paralic sediments, i.e. mixed continental, brackish water and marine deposits, which are covered by continental sands and gravels (fig. 2b). In cross section a time stratigraphic unit of such deltaic sediments is characteristically S-shaped (M e r k i, 1970).

In the paralic and continental intervals there are a few anomalous thick clay bodies which fill drowned valley systems. The latter may be associated with basement-related, epirogenetic movements.

The maximum depth to the basement may be as much as 12,000 metres. The continental sands have a maximum thickness of about 2,100 metres while the paralic sequence reaches a thickness of 3,000 metres in the centre of the delta (fig. 2b).

GROWTH FAULTS AND ROLLOVER STRUCTURES

The rapid sedimentation along the delta edge has resulted in the development of synsedimentary gravitational faults, the so-called "growth faults". Growth faults are well known from numerous publications on Gulf Coast tectonics (H a r d i n and H a r d i n, 1961; O c a m b, 1961; S h e l t o n, 1968). The exact way in which these faults are formed is not entirely clear but it is likely that gravitational slumping in undercompacted[2] marine clay plays an important part.

[2] In general the weight of the solids of the overburden is carried by the sediment grains while the pressure of the interstitial water is hydrostatic. However a rapid accumulation of poorly permeable clay and silt can prevent the escape of sufficient water to reach this equilibrium and

Clay diapirism in the form of ridges paralled to the coastline occurs also (fig. 2b).

Theoretical calculations and field observations show that the faults have a dip of 55° or more near the surface (Anderson, 1942). However, the faults are known to flatten considerably with depth which is in line with their superficial, sedimentary origin. The flattening of these faults, mechanically related to their mode of formation, has probably been accentuated by compaction. Thus a curved fault plane is developed which continues at a low angle in the mobile clay (figs. 2b and 3d).

Downward movement along the concave fault planes causes rotation of the downthrown layers and the resulting anticlines (figs. 3a and b) are called "rollover structures". In many such structures the rotation is associated with antithetic faulting.

Laterally the growth faults have a crescent shape, usually concave to the sea. This crescent shape also causes the layers to bend parallel to the fault and in this way elongated to egg-shaped anticlines are formed.

Both in Nigeria and along the Gulf Coast series of faults, which are more or less on strike, tend to grow together into long undulating fault trends, which run roughly parallel to the ancient coast lines. The major fault trends usually have several split-offs which can complicate the development of the rollover structure (fig. 3c). It is also common for the major fault trends to come together, or to be connected by additional faults (fig. 4).

In some cases the growth fault pattern may be related, at least partly, to collapse of the crest of the rollover structure above a rising mass of under-compacted clay (fig. 3d). The dip of the flanks of the rollover structures is generally only a few degrees except close to growth faults, were dips of 20° are not uncommon.

The growth faults only seem to be active near the coast and offshore. offshore they may even form a steplike relief on the sea bottom.

Movement along a fault tends to cease gradually when the sedimentation in the area of the fault has become entirely continental.

Growth faults are probably initiated by a locally

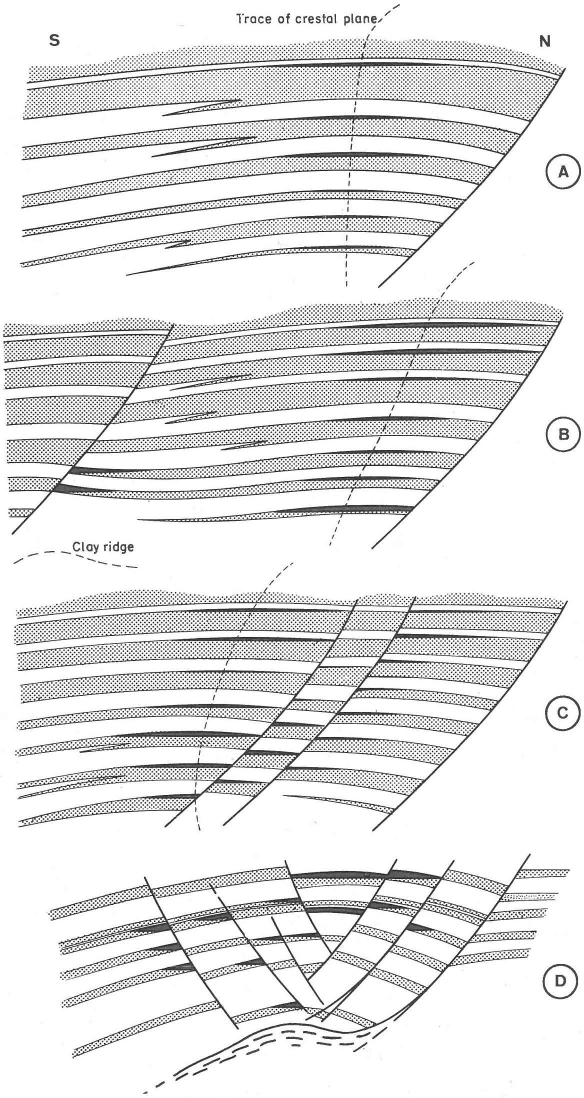

Fig. 3
Principal types of hydrocarbon traps associated with growth faults in the Niger delta.

very fast rate of sedimentation, the focal point of the fault crescent coinciding with the area of maximum sediment accumulation. In subsequent sedimentary cycles too the maximum sedimentation rate is often found close to this focal point (Murray, 1949). Opposite both ends of the growth faults, the sedimentation is less rapid and thus the sedimentary cycles tend to be somewhat lens-shaped. This lens shape is emphasized by the higher sand/shale ratio opposite the centre of the growth faults (fig. 4 and Short and Stäuble, 1967).

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consequently the fluid pressure is higher than hydrostatic. In a normal clayey sediment, accumulating at a rate of 10 cm/yr, a state of undercompaction can even be reached at a depth of less than 15 m.

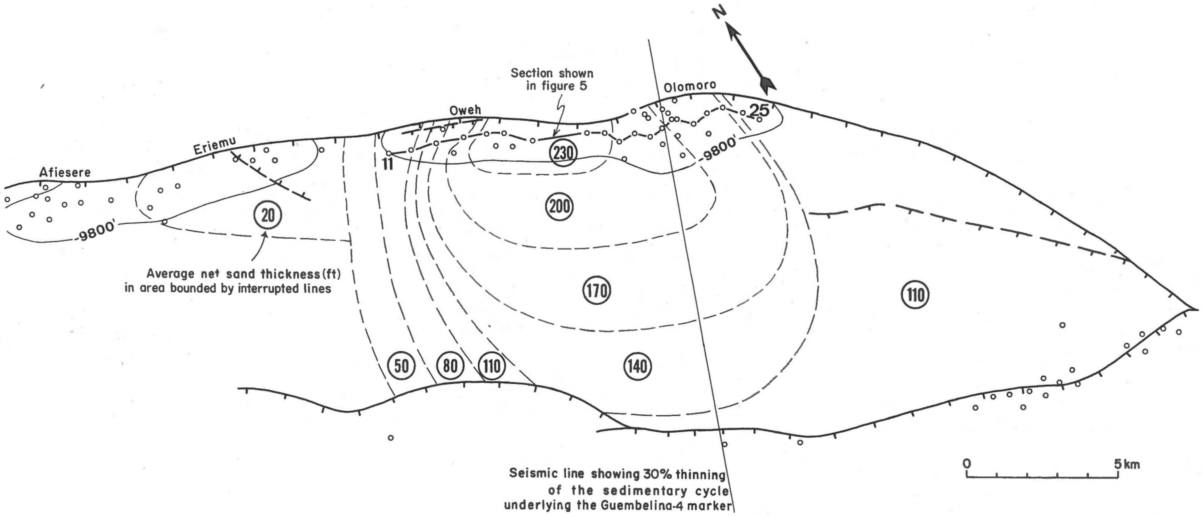

Fig. 4
Fault map of the Olomoro-Oweh fields area at the level of the Guembelina-4 marker, together with the measured and estimated net sand thickness in the underlying sedimentary cycle.

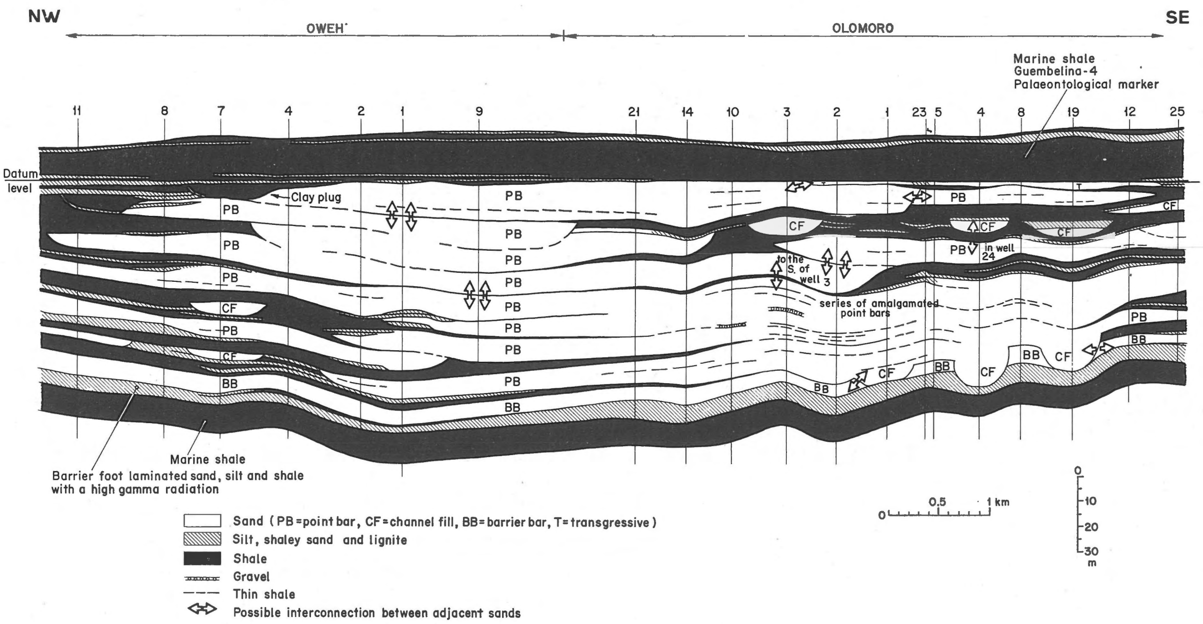

Fig. 5
Example of a thick lens-shaped sedimentary cycle mainly composed of point bar sands, Olomoro and Oweh fields.

In cases where a series of rollover structures is present along a growth-fault trend, the lens shape of sedimentary cycles can sometimes be observed because correlation is possible over a sufficient distance. An example is shown in fig. 5 which is a stratigraphic cross section of a thick sedimentary cycle in the twin fields Olomoro and Oweh. The sand thickness in the centre of the section is about 230 feet, tapering off to about 110 feet to the east and an even lower figure to the west. Differential compaction enhances the lens shape because of the lateral differences in the sand/shale ratio.

The closure of the structures parallel to the faults may well be mainly the result of the lens shape of the sedimentary cycles combined with differential compaction. Thus when the area with the maximum rate of sedimentation shifts in a lateral sense, the crest of the resulting anticline will shift in the same direction. Such lateral shifts of the crestal culmination are commonly observed in the Niger delta rollover structures.

Although several contemporaneous lenses of sand can be in lateral contact along a fault trend, the number of individual genetic sand bodies that continue from one lens into the next may often be limited. In the case illustrated in figs. 4 and 5 only one sand bed could be correlated with certainty from the Olomoro – Oweh area into the Eriemu field, viz. a 20 feet thick barrier bar of sand at the base of the sedimentary cycle (fig. 5). In certain cases the aquifer

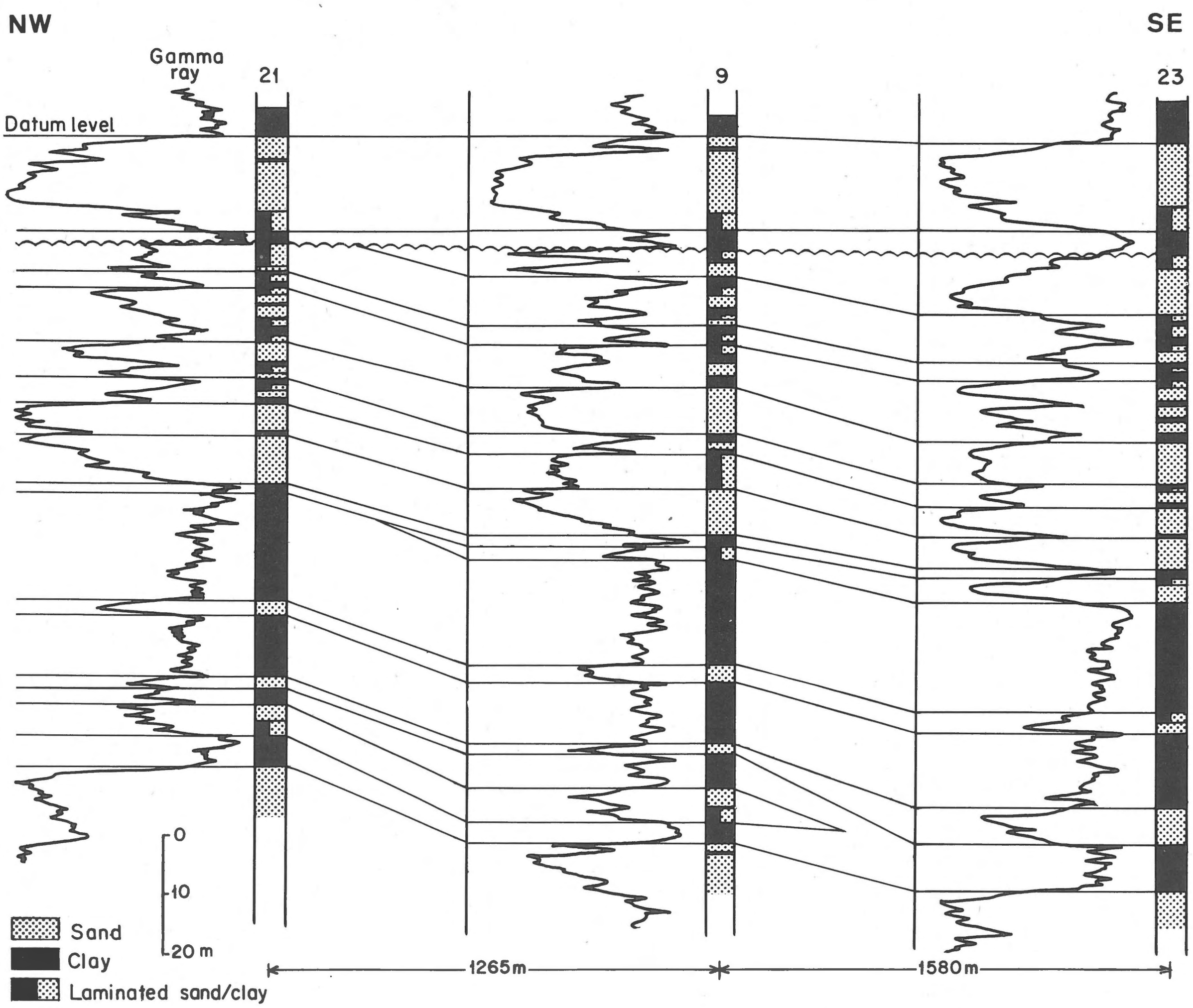

Fig. 6
Stratigraphic section through the Forcados Estuary field showing an unconformity caused by upward movement of the underlying marine clay.

of oil reservoirs may thus be restricted in size especially when the distance to the next growth fault in the coastal direction is small. A limited water drive is indeed observed in several fields.

The degree of faulting of the rollover structures varies across the delta in a complicated manner. The structures along the coast and offshore tend to be faulted more intensely than the structures further inland. The various types of oil accumulations associated with these different configurations are shown in fig. 3. The upward movement of clay ridges which is observed near the coast and offshore (fig. 3d) can cause unconformities, an example of which is shown in fig. 6. However only a few of such unconformities have as yet been identified.

An important aspect, typical for growth-fault regions, is the difficulty in correlating over large distances in a section perpendicular to the coast. The growth faults often have maximum throws of over 3,000 feet. This, coupled with the change in depositional environment in this direction and the large differences in thickness on either side of the faults, makes direct correlation of the logs difficult. Detailed paleontological and palynological analyses on shale samples are usually required to establish the stratigraphic relationships.

GEOMORPHOLOGY

The present geomorphology of the Niger delta has been described in detail by Allen (1964, 1965) and in the Nedeco reports (1954, 1959, 1961). Maron (1969) compared the Recent and ancient delta configurations. Furthermore several studies were carried out on the Recent sedimentation in the Niger delta region, both onshore and offshore, by geologists of Shell-BP and the Koninklijke/Shell Exploration and Production Laboratory. Many samples were taken offshore, while on land shallow core holes were drilled along the coast and in areas of predominantly fluviatile sedimentation. A typical example of this work is shown in fig. 7.

The assembled data have been combined in a model (fig. 8) in order to obtain a better understanding of the lateral and vertical development of the sand bodies in the subsurface paralic sequence. It has been assumed that the climate, oceanic currents

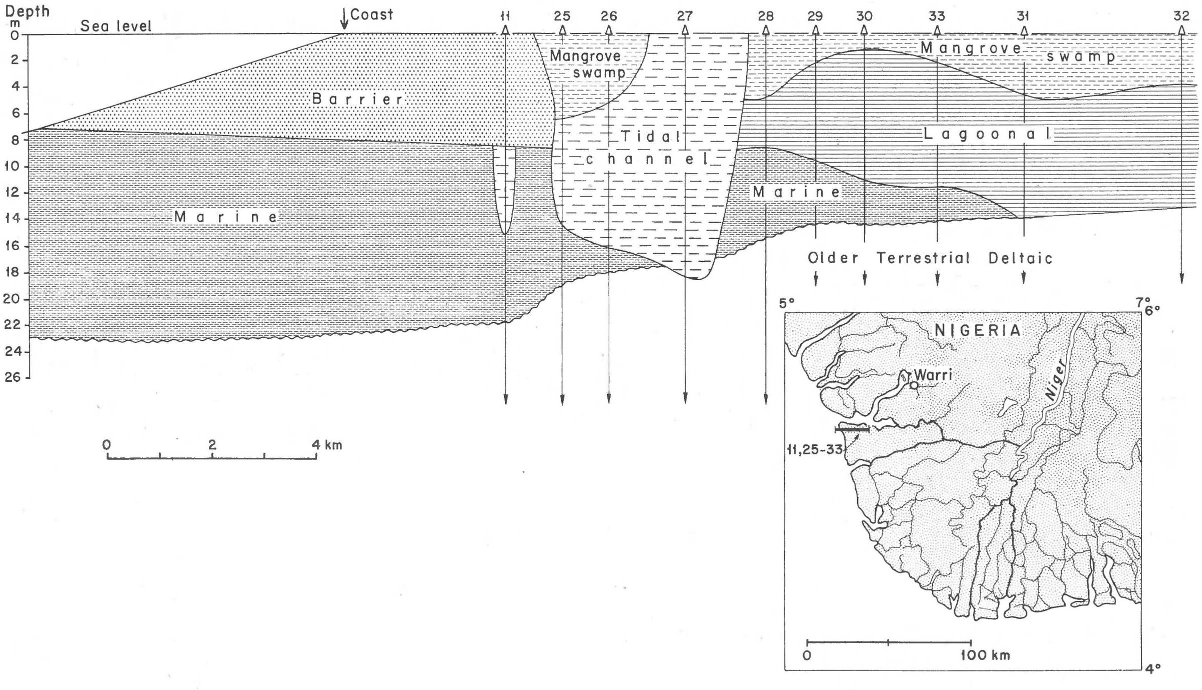

Fig. 7
Holocene deposits in core holes 11, 25-33, Nigeria (after J.P. v.d. Sluis, K.S.E.P.L.).

and tectonic activity have been more or less constant from the beginning of the Eocene to the Recent with the exception of the Pleistocene period. The Pleistocene regression and the post-Pleistocene transgression are events that complicate a direct comparison of the Recent and sub-Recent sedimentation with the Tertiary. This is especially due to the ensuing anomalously large distance from continental slope to the present-day coastline (50-60 km).

The following physiographic units can be distinguished in the Recent delta (fig. 8):

1. Holomarine zone in which predominantly clay is deposited and which ranges from the outer shelf up to a depth of about 30 metres. In certain areas lag deposits of the post-Pleistocene transgression are still lying at the surface.
2. A transition zone of either fluviomarine or barrier-foot sediments characterized by the deposition of laminated clay, silt and fine sand in a water depth ranging from about 30 to 10 metres. The silt and sand are transported by longshore currents which distribute the sediment load of the rivers along the coast.
3. Coastal belt of barrier bars consisting of fine to medium sand. The bars extend over and interfinger with barrier-foot sediments at a depth of roughly 10 metres. Again longshore currents are responsible for the transport of the sand. Beach ridges on the surface of the bar represent successive stages of growth. Peat can be formed in the swampy depression between the beach ridges. On the down-current end of barrier bars, sand spits extend into tidal channels which also belong to the coastal belt. River-mouth bars are formed in front of these tidal channels.
4. A tidal coastal plain extends behind the barrier bars and comprises tidal flats and swamps with dense mangrove vegetation which alternate with

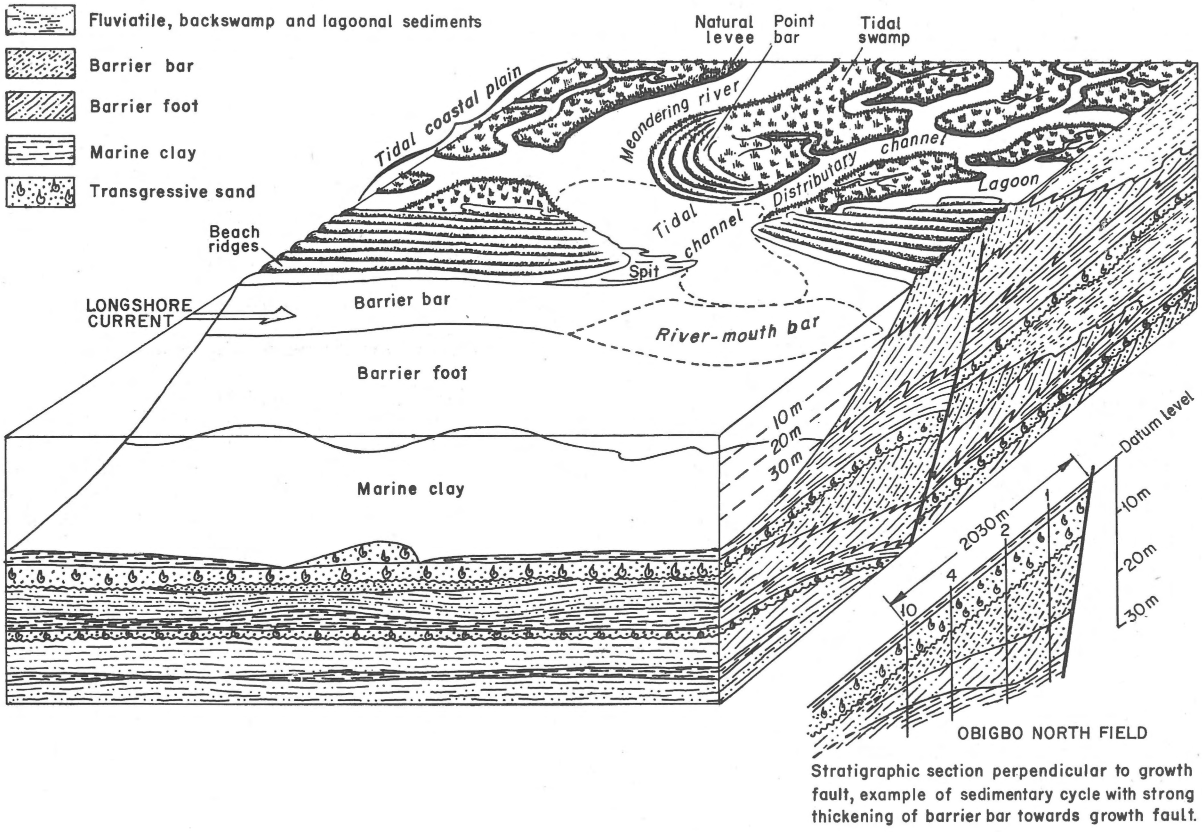

Fig. 8
Block diagram showing geomorphology, cyclic sedimentation and an active growth fault in the tertiary Niger delta coastal zone.

tidal distributary channels and lagoons. The distributary channels meander to varying degrees but this tendency diminishes near the coast. The sediments range from medium to coarse sand in channel fills via fine clayey sands in the natural levees to clayey, silty and peaty deposits in the swamps and lagoons. The edge of the tidal swamps moves seaward as the back of the barrier bars is eroded.

5. The flood plain of the major rivers contains an accumulation of medium to coarse point-bar sand and some clayey backswamp deposits.

From the studies of the Recent delta sediments, various criteria were derived for recognising the depositional environment of sands and clays in the subsurface. For the sands, the main criteria are based on the grain-size distribution, sedimentary structures and the authigenic minerals, e.g. glauconite. For the clays the faunal content, pollen analysis and clay mineralogy can be used. Studies based partly or entirely on observations in other areas are also of interest (L a g a a i j and K o p s t e i n, 1964; P o r r e n g a, 1967). The criteria which have proved to be most useful will be mentioned in the discussion of the various environments of deposition.

CYCLIC SEDIMENTATION

The vertical sequence of sediments in the shallow core holes in the Recent and in the deep boreholes in the Tertiary paralic deposits show clearly the characteristic cyclic nature of the sedimentation. The Tertiary paralic sediments are composed of a large number of depositional cycles with a thickness ranging from 15 to 100 metres. Cycles more than 60 metres thick are not common.

A complete cycle generally consists of a thin fossiliferous transgressive marine sand followed by an offlap sequence which commences with a marine shale and continues with laminated fluviomarine sediments. Barrier-bar and/or fluviatile sediments may follow before another transgression terminates the cycle. This type of cycle is also known from other deltas described for instance by K r u i t (1955) and O o m k e n s (1967).

In fig. 8, the cyclical build-up of the delta has been reconstructed. A growth fault has been incorporated in the model to illustrate the influence of the rapid sedimentation along the downthrown side of the fault. Beneath the block diagram a section has been sketched through a cycle in the Obigbo North field which shows that over a distance of about 2 km the sand thickness of a barrier bar can more than double probably mainly as a result of the growth fault.

The composition of a given cycle observed in an oil well of course depends greatly on the location of the well with respect to the relevant ancient coastline. In oil fields which are fairly wide perpendicular to the main growth fault, the lateral changes in the depositional environment of the sediments of each cycle can be observed. An example of this is shown in fig. 9 which is a schematic N-S cross-section with a length of about 5 km through a series of four cycles in the Bomu field (see also F r ä n k l and C o r d r y, 1967, p. 204-205). In this case a transgressive sand is developed at the top only of the uppermost cycle, but on top of the underlying cycle a basal conglomerate of clay-ironstone pebbles is present. The lower two cycles are only partly developed within the field area.

In many cases, such as in the series of cycles in the

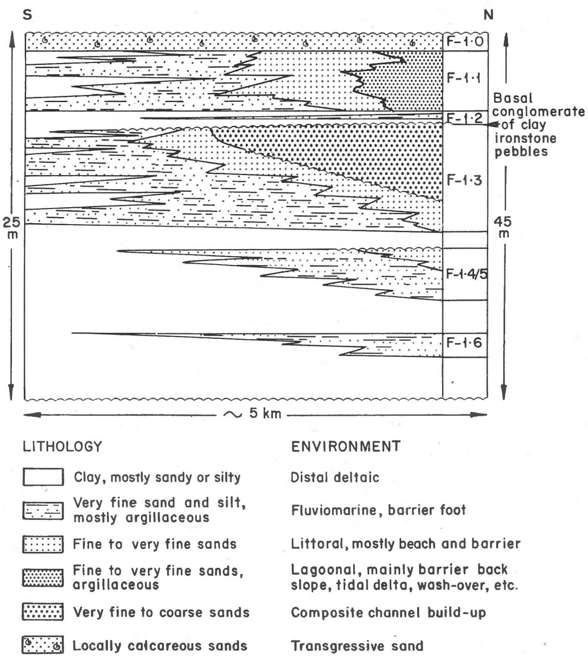

Fig. 9
Schematic representation of the facies distribution within the f-1 sands of the Bomu field (after B. v. Rossum).

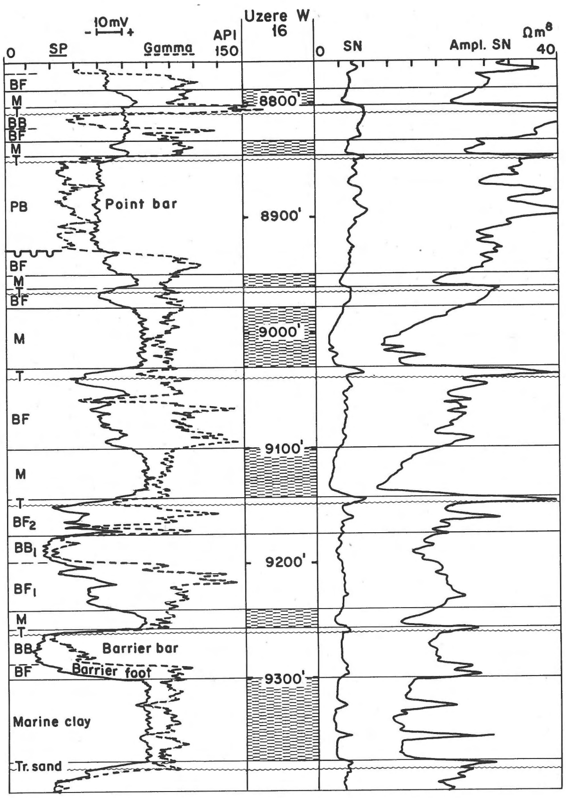

Fig. 10
Example of a series of offlap sequences in the paralic sequence Uzere West field.

Uzere West field shown in fig. 10, the successive cycles are all fairly complete. Although the depositional environment within the sandy part of the cycles may change, the cycles themselves can readily be recognized from the petrophysical logs. This is especially so when the properties of the various types of deposits are related to the log response.

ONLAP SANDS

Most cycles begin with the erosion of the underlying sand unit and the deposition of a thin fossiliferous transgressive marine sand. These sands can be recognised by their relatively high resistivity because their pores are partly filled with carbonate cement. Often the gamma radiation emitted by the transgressive sands is also high (e.g. in the topmost cycle in fig. 10) due to a high percentage of the potassium-rich glauconite.

The transgressive sands are mainly derived from reworking and winnowing of the eroded beds. In addition, the gravelly sands contain an abundance of debris such as shale fragments, foraminifera, bryozoa and fish otoliths. Burrowing extending into the underlying offlap sand is common. This type of transgressive sand is probably associated with a regional transgression which pushed the shoreline back over a considerable distance. In consequence the fluviomarine sediment sources were too far away and deposition of clastic particles is very slow. The presence of abundant glauconite is indicative of slow marine deposition (P o r r e n g a, 1967).

There is also another less common type of onlap deposit which is generally thicker than the above type, viz. up to 10 metres instead of up to about 3 metres. In this type of onlap sand the contact between the onlap and underlying offlap sediments is less erosive. The onlap seems to have taken place more gradually and the onlap sands have the character of fluviomarine sediments. However instead of the normal upward coarsening of the fluviomarine deposits, these onlap sands become finer upwards and finally grade into marine clay. Streaks of coarse grains and glauconite and clay intercalations are common. This type of onlap may be associated with strong growth-fault activity in a limited area. The transgressive sand in the Agbada field cycle shown in figure 12 is of this type.

OFFLAP SEDIMENTS

Marine clay: The marine clay overlying the onlap sands is usually quite silty and sandy. A gradual decrease of faunal remains and a diminishing diversity in species indicates an upwardly increasing sedimentation rate. Burrowing is common and the original layering is usually destroyed. Streaks and lenses of very fine sand to silt occur throughout; clay and plant remains can be abundant. The faunal interpretation, combined with the occasional abundance of plant remains indicate that the clays were deposited in the inner to middle neritic zones.

The marine clay contains significant amounts of montmorillonite which is finer than kaolinite and thus transported further. In all other clays kaolinite is the only important clay mineral.

The marine clays are of great importance with respect to the hydrocarbon accumulations because they form the seal over the top of the reservoirs.

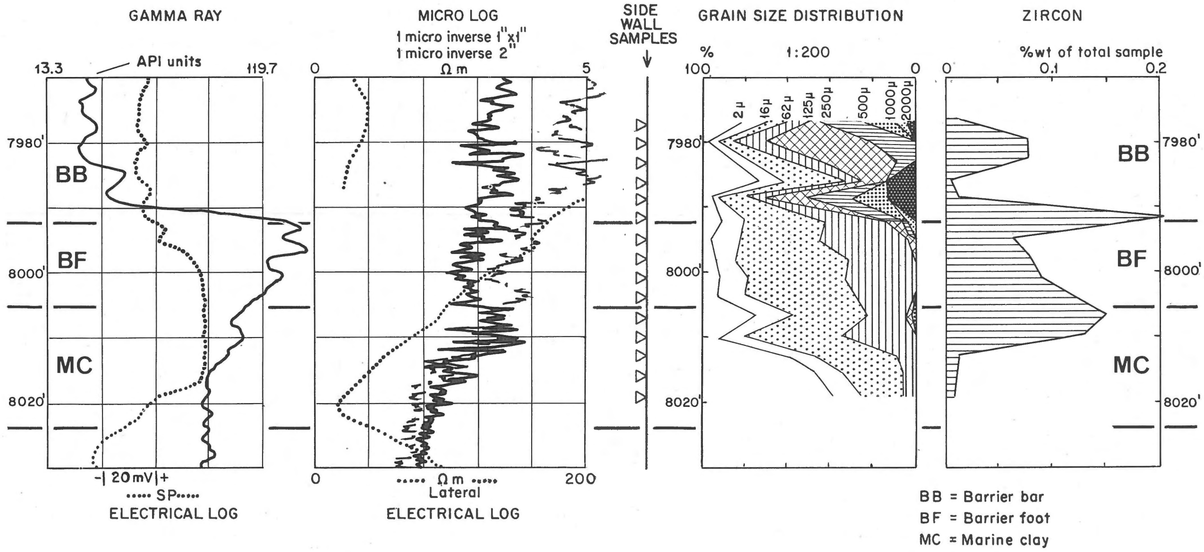

Fig. 11
Interpretation of high gamma radiation of barrier foot sediments in well Olomoro-5 (after M.B.K. Lutz).

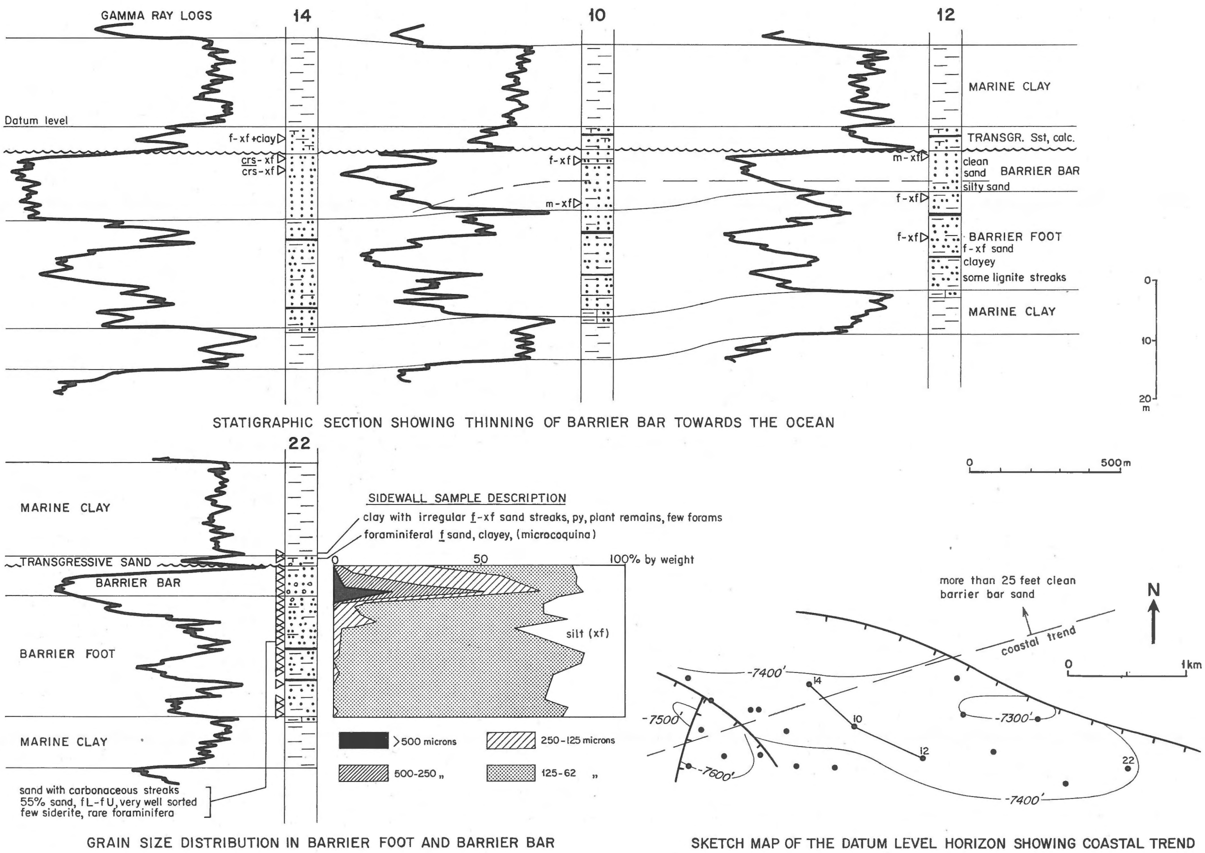

Fig. 12
Example of lateral development of barrier sand sequence in the Agbada field.

FLUVIOMARINE (DELTAIC FRINGE) AND BARRIER-FOOT DEPOSITS

Towards the top, the marine clay becomes more sandy and gradually changes to laminated clay/silt/ fine sand. Because of the rapid sedimentation the layers are little disturbed by burrowing. This is of interest because this part of the offlap cycles is deposited on a very flat slope. Thus after folding in a rollover structure, these intervals can be used for deriving accurate structural dips from the dipmeter logs.

Gradually the fluviomarine character becomes more pronounced; the sand laminae thicken and the average grain size increases; plant remains are very common and occasionally accumulate in thin lignitic streaks. This type of sediment often forms the proximal fluviomarine frontal part of coastal barriers and is termed "barrier foot".

A remarkable feature of the "barrier foot" deposits is the high gamma radiation commonly associated with these beds. In fig. 10, the "barrier foot" gamma radiation is often higher than that of the marine clay. A study was made of the origin of this radiation by analysing a series of sidewall samples from a high radiation zone of this kind in the Olomoro field (fig. 11). The source of the radiation appears to be the high percentage of silt size zircon. Zircon contains in general from 200 - 2,000 ppm Th and from 600 - 6,000 ppm U.

BARRIER BAR

The barrier foot is often overlain by the higher-energy barrier beach and washover sands. The cleaner and coarser sands deposited in the zone where wave action takes place are termed "barrier bar" deposits. The sands are fine with an average grain size of 250-60 microns. The sorting of the sand varies considerably. Of more diagnostic value is the ratio of maximum (D1) to average grain size (D50) which ranges from 1 to 3. In the fluviatile sediments of the Niger delta this ratio is always higher than 3.

The main part of the barrier bars is usually parallel bedded with occasional small-scale cross-bedding in the lower part and a limited number of burrows. Silty clay breaks and lignite beds are common. Most of the peat is formed in the swampy depressions between the beach ridges (A l l e n, 1965 a). The formation of the barrier bars by longshore currents and wave action is a well known process.

A l l e n (1965 a) also describes the erosion of the landward side of the barrier bars by tidal channels (fig. 8). However the remaining barrier-bar sands are usually still several kilometres in width (an average of 5 km in the Recent delta). The length of the barriers parallel to the coast is very large (5 - 37 km with an average of 18 km in the Recent delta). Thus the barrier bars have the character of widespread sheet sands.

The majority of the oil fields have a width perpendicular to the coastal trend of 2 km or less and a length of less than 8 km. Barrier bars encountered in a field can thus in general be correlated over all or most of a field's area. In the case illustrated in fig. 4 and 5, the barrier bar near the base of the cycle could be correlated over a length of 21 km parallel to the growth fault, from the eastern end of the Olomoro field up to the Afiesere field. Since the sand thickness is about 6 metres, a length/thickness ratio along the fault of several thousand is obtained.

The sand thickness of a barrier bar is generally not much greater than about 12 metres except near growth faults as shown in fig. 8. This is because at a water depth of over 10 metres predominantly shale interbedded barrier-foot deposits are formed. In fields that are relatively wide perpendicular to the coastal trend one can often observe a reduction of the thickness of the clean barrier-bar sand in the seaward direction of the type shown in the model (fig. 8). A good example is a cycle in the Agbada field (fig. 12). In this example the high gamma radiation of parts of the barrier foot and the upward coarsening of the barrier sequence is also shown.

The upward coarsening is often fairly gradual and is reflected by gradual changes in SP log and gamma-ray log response. This coarsening is almost always accompanied by an upwardly increasing permeability. Thus in oil-bearing reservoirs of this type the resistivity generally increases in an upwards direction.

Clay breaks in the barrier bars, unlike clay breaks in fluviatile sediments, can often be correlated over large distances. These continuous clay breaks reduce the vertical permeability of many barrier-bar reservoirs.

It is fairly common to find a series of barrier-bar sands on top of each other with only a very thin marine clay and/or a thin interval of barrier-foot sediments in between the clean sands. Such a succession of genetic units of the same type is termed an amplified sand body and is generally the result of rapid subsidence during the deposition.

In places where a barrier bar is eroded by distributary channels, as in the bottom part of the cycle in fig. 5, so-called composite sand bodies are formed which consist of more than one type of genetic unit.

TIDAL CHANNELS

At present many estuaries and tidal channels are found along the delta coast. The maximum width of the tidal channels is 2,700 metres with a depth of 20 metres. The width/depth ratio ranges from 38 to 200. Although tidal channels tend to migrate, the subsurface width/thickness ratio of tidal channel-fills is probably in the same range. In fig. 7 the section crosses the tidal channel obliquely; the width in the section is about 3,500 metres and the thickness about 17 metres, i.e. a width/thickness ratio of about 200.

Tidal channel-fills often consist of a series of thin cross-bedded sequences fining upwards with a clay pebble or gravelly lag deposit at the base, and separated by thin clay beds. The grain-size distributions are similar to those of fluviatile deposits in the lower deltaic plain. Clay breaks between these sequences give the channel-fills a serrated character on the SP and gamma ray logs. The clay breaks are generally difficult to correlate in contrast to the very

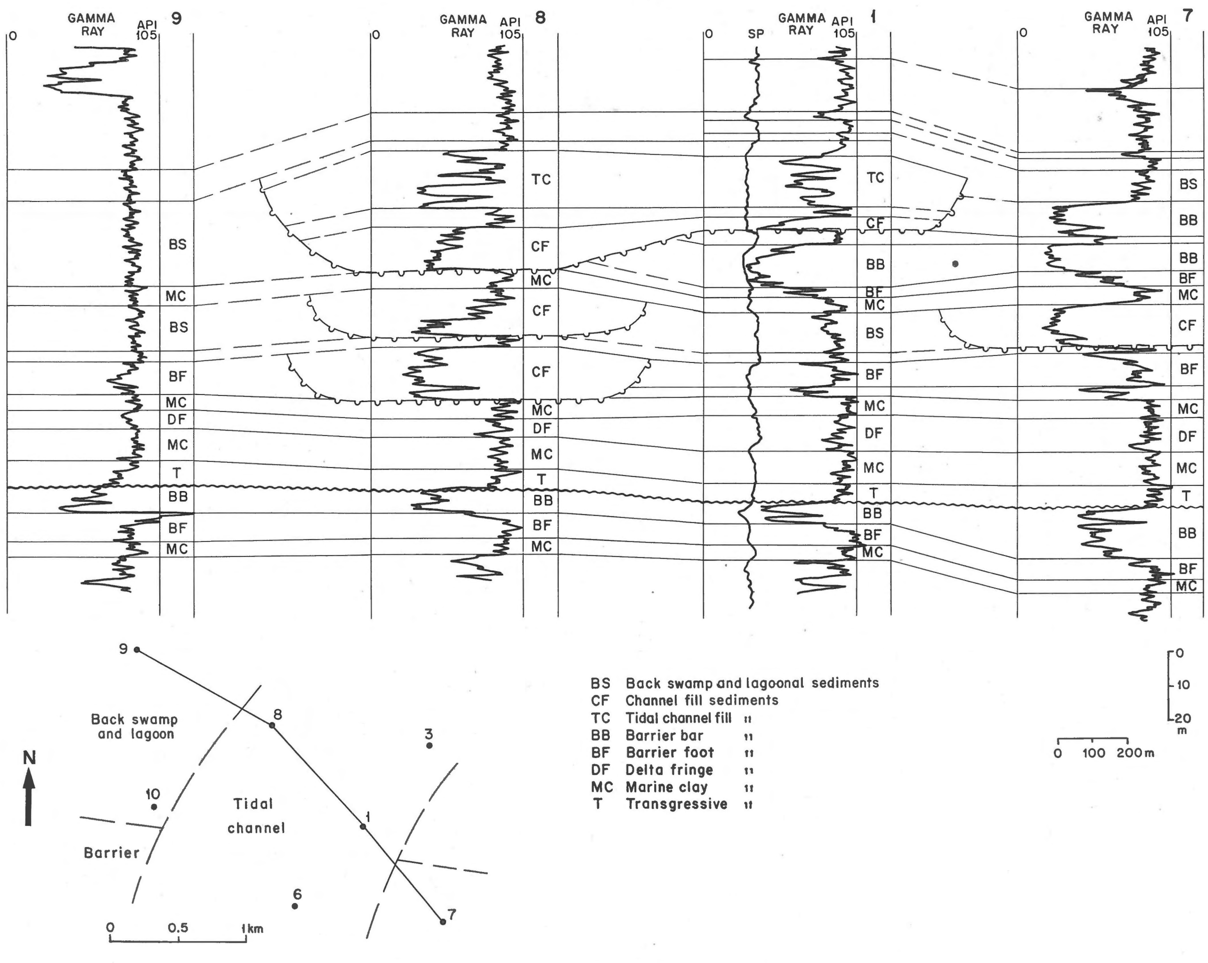

Fig. 13
Stratigraphic section through a part of the Egwa field paralic sequence, showing a tidal channel-fill.

continuous clay breaks in barrier bars. The sequences which fine upwards sometimes show up clearly on the micrologs.

Fig. 13 shows a tidal channel in the Egwa field. A distributary channel apparently developed into a tidal channel. The section runs at an angle with the coastal trend. Thus on one side the channel-fill is flanked by clayey backswamp and lagoonal deposits while on the other side we find the barrier bar through which the channel eroded its way. Thus the section is very similar to the one through Recent sediments shown in fig. 7. The effect of differential compaction is very marked. The width/thickness ratio of the composite distributary and tidal channel-fills is about 50 (about 1,500 metres wide and roughly 30 metres thick on average).

The river-mouth bars associated with the tidal channels have occasionally been identified in cores. Their characteristics and position in the cycles, however, are rather similar to barrier bars and the difference is difficult to see on log evidence alone.

FLUVIATILE DEPOSITS

The fluviatile deposits are best followed from inland to the coast, i.e. from the river flood plains to the coastal distributary channels.

In the flood plains the meandering rivers gradually occupy every possible position in the river valley at least once. This results in a brickwork of point bars, as shown in fig. 5. Some clayey beds may be left between overlapping point bars but sometimes thick continental sheet sands are formed. In the paralic sequence, the maximum sand thickness of an amplified pointbar sand body is usually not larger than 100 metres, build up by point bars which are each about 8 to 15 metres thick.

Fig. 14 shows the SP and gamma ray logs of the cycle in fig. 5, recorded in the well Olomore-21. In this case the point bars have a fairly constant low gamma radiation throughout while the SP response is also quite constant. Because the fluviatile sediments have a characteristic upward fining grain-size distribution one would expect an upward development of the log response which is the opposite of that observed in barrier bars. However the upper, more clayey part of the point bars is often eroded away in such "amplified" point-bar sand bodies.

A very clear indication of the erosive character of the fluviatile sand bodies is the sharp base of the sand units in the logs. Occasionally however clay pebbles at the base of the sand may obscure this log effect.

The width/thickness ratio of the point bars in fig. 5 ranges from about 400 to 800 which is roughly the range to be expected for point bars. At one side the oval point bars are often terminated by the clayey fills of the Oxbow lakes (fig. 5).

Backswamp deposits consisting of silty clay, thin sand beds, (e.g. small creek fills) and peat are commonly preserved between and beside point-bar sands. Further away from the axis of the river valley they can become prominent.

Closer to the coast on the tidal flats the rivers subdivide into many distributaries. Most of these distributary channels also have the tendency to meander but many more or less straight channels are

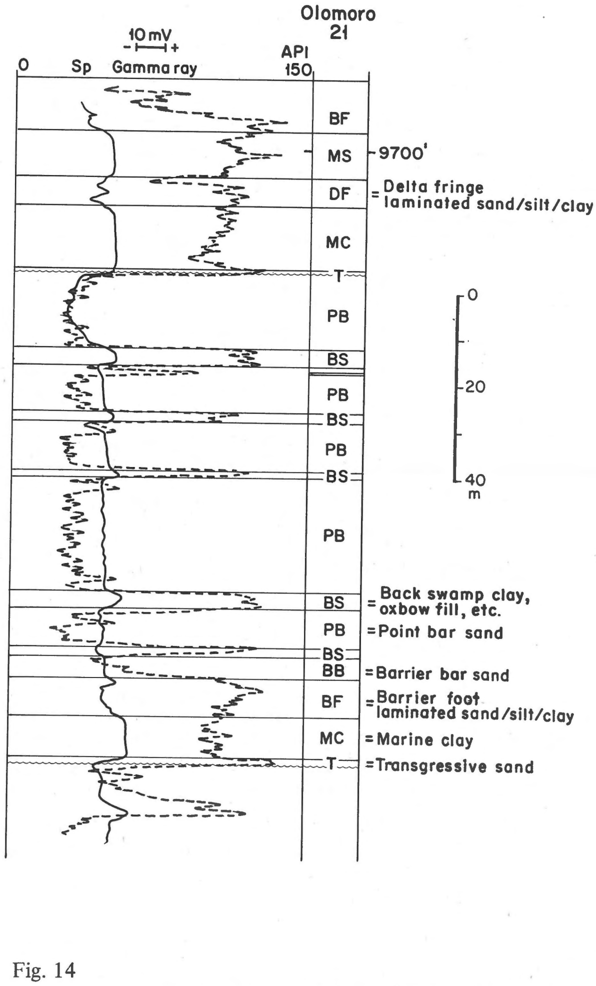

Fig. 14
SP and gamma ray logs of a thick predominantly fluviatile cycle in the well Olomoro-21.

observed in the Recent. The result is that the distributary channels either form point-bar deposits similar to those described above or that channel fills of limited width such as the one shown in fig. 13 are formed. Thus the width/thickness ratio varies considerably. For the straight to moderately migrating channels the width/thickness ratio should range from 25 to 250.

Distributary channel fills are very similar in grain-size distribution and internal structure to point-bar sands formed further away from the coast. Amplified distributary-channel sands are not very common. However they frequently form composite sand units where they have eroded their course through barrier sediments.

In the distributary-channel fills the upward fining grain-size distribution is often pronounced in the upper part of the fills which are commonly composed of laminated wavy-bedded clay and silty sand often followed by kaolinitic root-marked clays. Plant remains and clay pebbles are common.

Around the distributary-channel fills natural-levée deposits of clayey fine sand and crevasse sands are found interbedded with the backswamp and lagoonal sediments.

Prominent distributary-channel fills are often found to cross the rollover structures near the crest. This may be related to the influence of the growth faults on the sand distribution mentioned above.

PRACTICAL USE OF SEDIMENTOLOGICAL INFORMATION

When an exploration well discovers hydrocarbons the next step is to estimate the lateral development of the reservoirs. This is partly a structural problem but the sand thickness distribution and the possible variations of the petrophysical properties are related to the depositional environment of the rock. When more wells have been drilled a sedimentological study is often useful to obtain the correct correlation. To choose additional appraisal-well locations an estimate of the lateral extent of the reservoirs is necessary. The continuity of clay breaks can often be predicted when the depositional environment of a reservoir is known.

The different types of reservoir rocks such as channel fills and barrier bars have characteristic permeability distributions both vertically and laterally. Thus in the study of gas or water coning and other reservoir engineering subjects the reservoir type has to be known.

The majority of the reservoirs in Nigeria consist of poorly consolidated sand. Wells are usually completed by perforating a 6 foot intervals after which the sand around the casing opposite the perforations is consolidated artificially with Epikote resin. For this purpose a homogeneous interval has to be selected which demands good knowledge of the significance of variations in the log responses. This is also necessary to appraise the sealing capacity of inhomogeneities in a reservoir or of intercalations between successive reservoirs. By a good choice of the completion interval above or beneath an intercalation with the correct properties the break-through of water or gas into the well may be considerably retarded.

The necessary lithological and petrophysical data can of course be obtained by coring each reservoir in a number of places. However because of their very large number, coring is restricted to the most important reservoirs. Thus in general the environment of deposition and the petrophysical properties have to be derived from logs together with a certain number of sidewall samples. Fortunately the recovery of sidewall samples is usually very satisfactory.

To illustrate this approach an example has been selected which incorporates many of the above aspects, viz: a series of four sedimentary cycles in the Afiesere and Eriemu fields which contain several types of reservoirs and a complex oil distribution (fig. 15). The oil is quite viscous in this case and a good knowledge of the permeability distribution in the various sands is necessary to select completion intervals.

According to the log character, the continuity of the sands and the sidewall-sample descriptions, the sands of the lowest cycle (I) are typically fluviatile. The sands are poorly sorted with a grain size ranging from very coarse to very fine. This is probably an amplified point-bar unit deposited by meandering distributaries, that have eroded almost to the marine clay of this cycle. Over most of the fields the amplified unit is two point bars thick except near the well Afiesere-12 where three point bars can be distinguished.

This type of reservoir typically contains only discontinuous clays between and within the point bars. Thus the sands are in good communication with each other. Furthermore the unconsolidated fluviatile

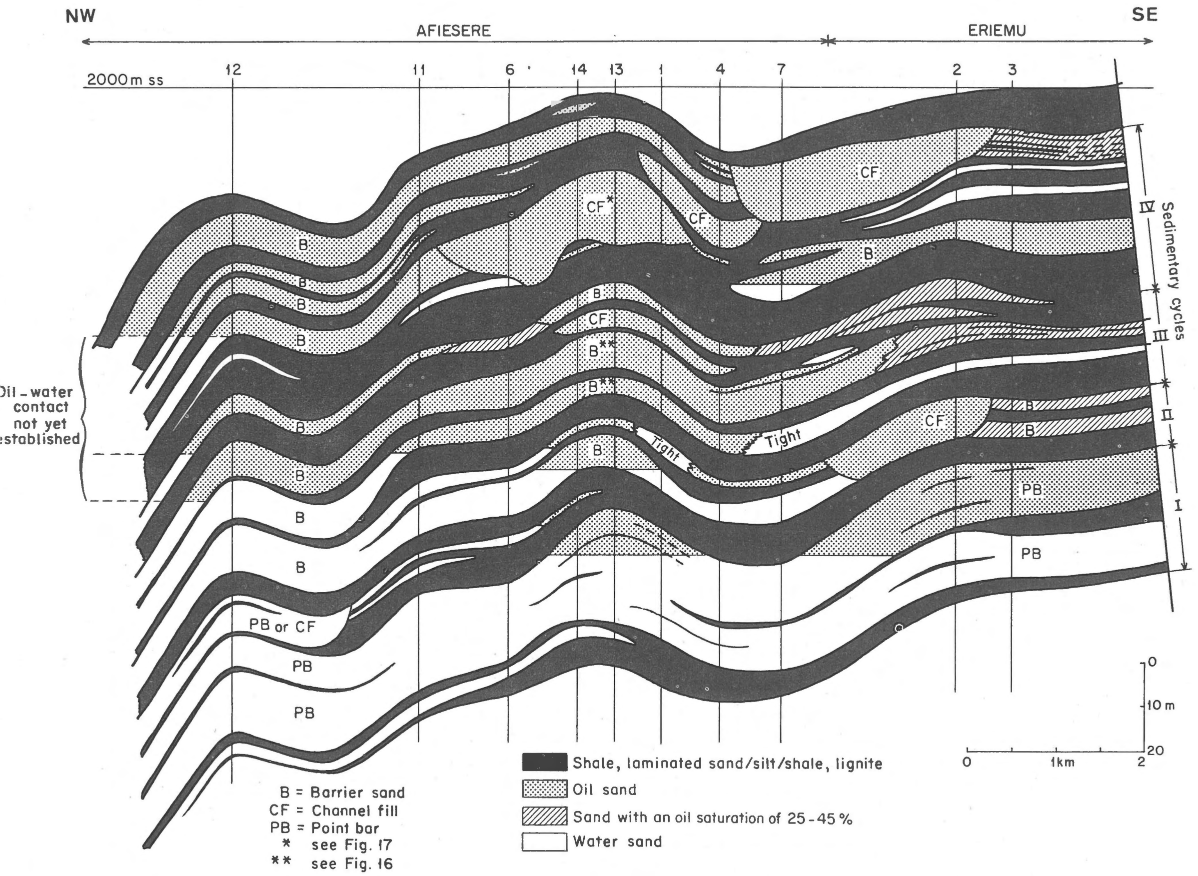

Fig. 15
Example of a complex hydrocarbon distribution in a series of four sedimentary cycles in the Afiesere and Eriemu fields.

sands nearly always have a high permeability throughout. Consequently the oil-filled culminations in Afiesere and Eriemu have high average oil saturations. The average porosity of such a unit is usually remarkably constant from one end of the field to the other.

The thin natural-levée or crevasse sand attached to the upper-most point bar (or channel fill) in the well Afiesere-12 contains some stratigraphically trapped oil near its tip (Afiesere 14). Such small irregular oil accumulations are common.

The next cycle (II) is much more complex. It consists principally of two barrier-bar sands which again form an amplified unit. Furthermore in the Eriemu field there is also a distributary-channel fill. Logs and sidewall sample analysis indicate that the lowest barrier has a high porosity and a fairly good permeability. It contains a small structurally trapped oil accumulation.

However the uppermost barrier sand is cemented by secondary carbonate derived from the disconformably overlying fossil-rich transgressive deposits. The porosity and permeability are much reduced and the bed contains tight zones with very little oil. In sands of this type an irregular oil distribution is to be expected. Productivity from such a reservoir will in general be poor.

The channel-fill eroding the two barrier sands has the best permeability of the sands in the cycle because of its much larger average grain size which together with the log response make it stand out clearly from the surrounding barrier sands. This channel-fill has a good oil saturation and can be expected to produce well. Updip to the SE the continuation of the barrier sands do contain some oil but in both cases the petrophysical properties have deteriorated seriously. This lateral deterioration of barrier sands is often observed in long sections and is

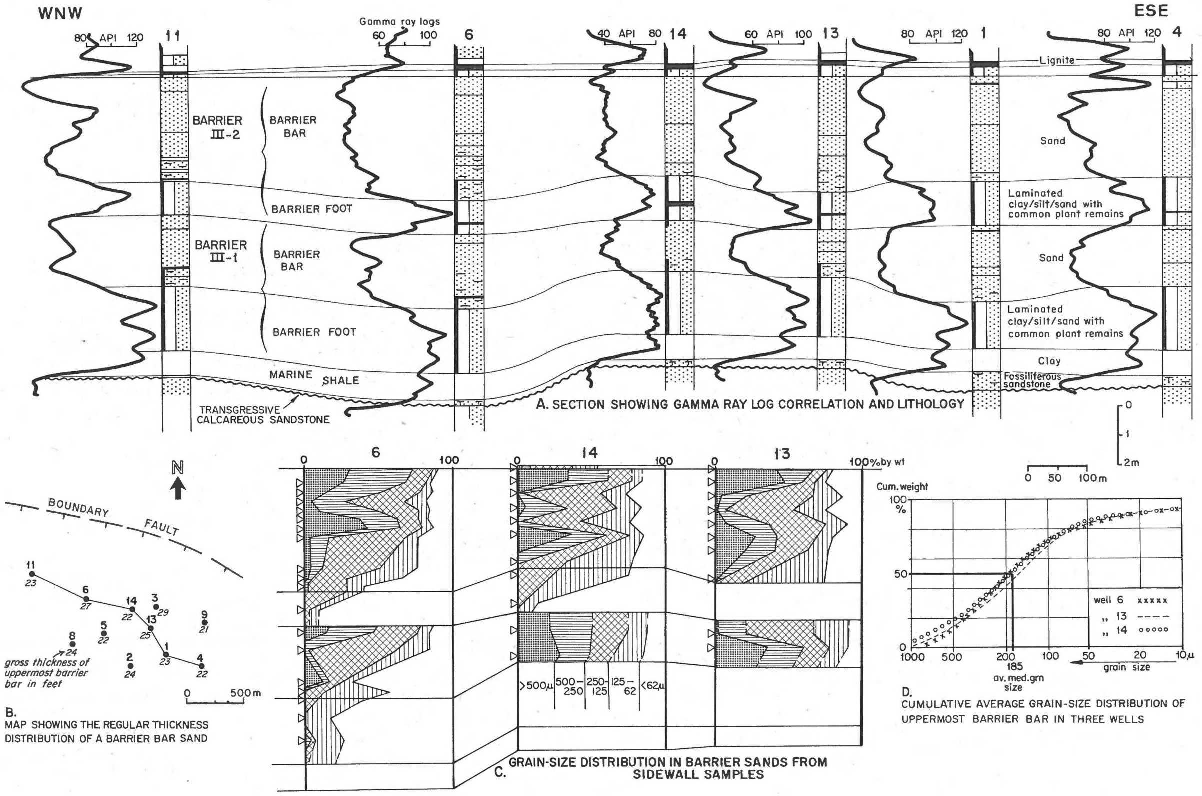

Fig. 16
Example of a depositionary cycle including two barrier sands (Cycle III of Fig. 15).

usually related to the pinch out from barrier-bar into barrier-foot deposits (see fig. 8, 9 and 12).

The next cycle (III) contains important oil reserves in a series of three barrier sands with one small channel fill between the upper two barrier sands. In all three barrier sands the oil accumulations are terminated in the updip direction in the manner discussed above.

A detailed correlation of the central part of the lower two barriers is given in fig. 16a. The typical gamma-ray log response for an amplified barrier unit of this kind is clearly shown. The regular thickness distribution of a barrier-bar sand is demonstrated in fig. 16b. In fig. 16c the grain-size analysis is given of series of sidewall samples from three wells. The coarsening upward of the sand is very clear. The upper parts of the sands are coarser than usual probably because of the presence of nearby tidal passes.

The sorting is poor because of the admixture of the coarse and medium sand and the permeability of the sands is much less than in the channel fill sand of the cycle. The channel fill is also poorly sorted but the average grain size is much larger. In this case the cumulative average grain-size distributions of the uppermost barrier bar sand which is given in fig. 16d shows an anomalous coarse tail which is not usually present in barrier sands. However there is no question about mistaking this sand for a channel fill because of the typical upward coarsening sequence. The uppermost cycle (IV) is the most complex one. It is again composed of an association of barrier and channel-fill sands. Two large channel fills with width/thickness ratios of about 200 and a smaller channel fill in between are prominent in the highest part of the structure. To the NW almost all barrier sands appear to be in communication with these channel fills, while to the SE the barriers are mostly isolated. Obviously the correct correlation of such a complex unit is difficult and lithological evidence is needed to identify the various depositional types.

Again a detailed section is presented of a part of

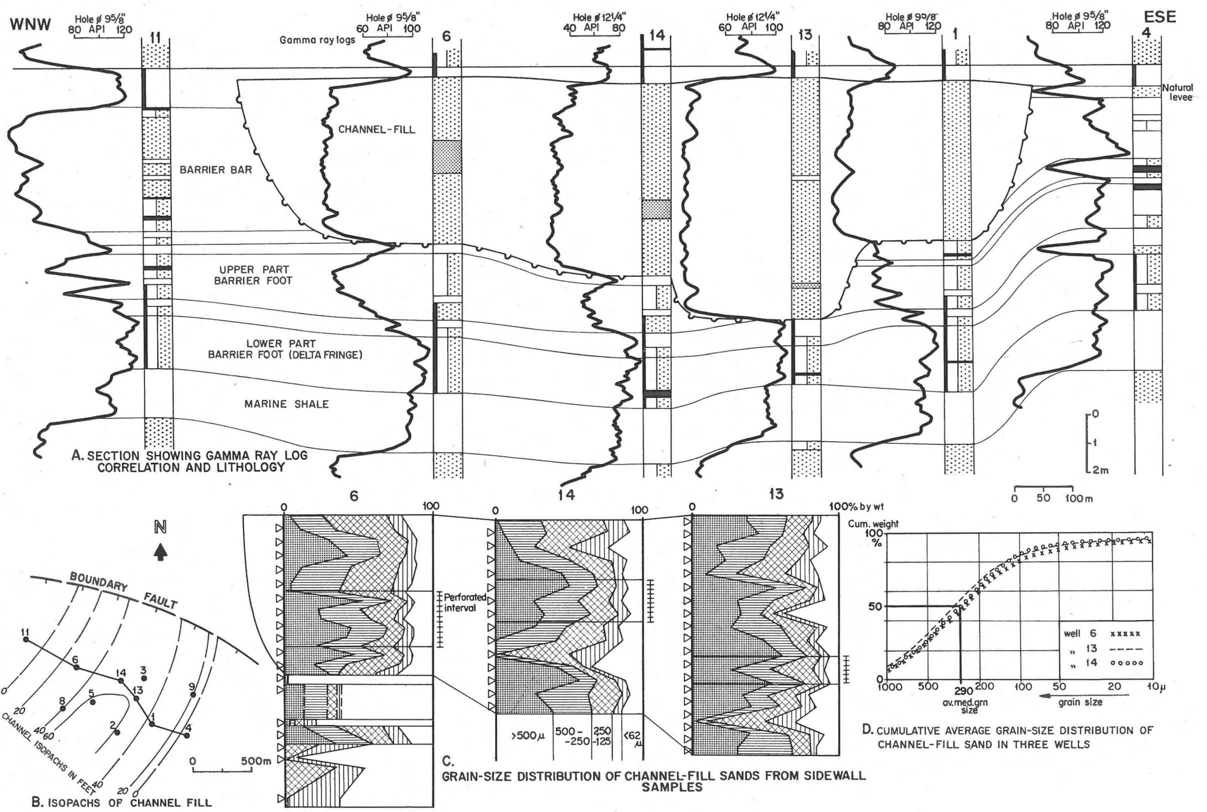

Fig. 17
Example of large distributary channel-fill, illustrating the higher productivity of channel compared with barrier sands (Cycle IV of Fig. 15).

this cycle, viz: of the large channel fill in the centre and its neighbouring beds (fig. 17a). The difference in log response of the channel fill and the barrier sands is striking. The effect of the differential compaction when one compares the thickness of equivalent intervals in the Wells 1 and 4 is also interesting.

The typical isopach map of a channel fill of this type is shown in fig. 17b. The grain-size distribution of series of sidewall samples from three wells is given in fig. 17c. A comparison with fig. 16c will illustrate the difference between the vertical grain-size distribution in a channel fill and in barrier sand.

In this case fig. 17c was primarily used to select optimum intervals for perforation. An empiric relationship between average grain size, sorting and porosity (from compensated formation-density logs) provides an estimated permeability distribution. The most permeable intervals were perforated as shown in fig. 17c. Because of the high viscosity of the oil this selection was essential to obtain satisfactory productivities. Typically the completion in the barrier-bar sand in well-11 produces only a tenth of the daily production of a channel-fill completion. This emphasizes the need to comprehend the nature of the reservoirs at an early stage.

CONCLUSION

The extensive studies of the Recent sediments of the Niger delta, similar studies of other deltas and the detailed analysis of the subsurface information together provide a wealth of data which have great economic value in the development of oil fields in Nigeria.

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REFERENCES

Allen, J.R.L. (1964) – Sedimentation in the modern delta of the River Niger, West Africa. In Deltaic and shallow marine deposits (Ed. L.M.J.U. van Straaten). Developments in Sedimentology 1, Elsevier, Pub. Comp. Amsterdam, p. 26-34.

—— (1965, a) – Coastal geomorphology of Eastern Nigeria: Beach-ridge barrier islands and vegetated tidal flats. Geol. en Mijnb., 44, p. 1-21.

—— (1965, b) – Late Quarternary Niger delta, and adjacent areas: sedimentary environments and lithofacies: Am. Assoc. Petrol. Geol. Bull., 49, p. 547-600.

Anderson, E.M. (1942) – The dynamics of faulting and dyke formation. Oliver and Boyd, Edinburgh and London.

Fränkl, E.J. and E.A. Cordry (1967) – The Niger Delta Oil province: Recent Developments Onshore and Offshore. Proceedings of the Seventh World Petroleum Congress, p. 195-209.

Hardin, F.R. and G.C. Hardin, Jr. (1961) – Contemporaneous normal faults of Gulf Coast and their relation to flexures: Am. Assoc. Petrol. Geol. Bull., 45, p. 238-248.

Kruit, C. (1955) – Sediments of the Rhone delta. I. Grain size and microfauna. Verh. Kon. Ned. Geol. Mijnb. Gen. Geol. Ser. 15, p. 357-514.

Lagaaij, R. and F.P.H.W. Kopstein (1964) – Typical features of a fluviomarine offlap sequence. In Deltaic and shallow marine deposits (Ed. L.M.J.U. van Straaten). Developments in Sedimentology 1, Elsevier Pub. Comp., Amsterdam, p. 216-226.

Maron, P. (1969) – Stratigraphical Aspects of the Niger Delta. Jour. Mining and Geology, 4, Nos. 1 & 2 p. 1-12.

Merki, P.J. (1970) – Structural Geology of the Cenozoic Niger Delta. Proc. First Conf. on African Geology, Ibadan University of Nigeria (in press).

Murat, R.C. (1970) – Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in southern Nigeria. Proc. First Conf. on African Geology, Ibadan University of Nigeria (in press).

Murray, G.E. (1949) – Geosynclinal sedimentation in central Gulf region of United States: Oil and Gas Jour. 48, No. 25, Oct. 27, p. 87.

Nedeco (Netherlands Engineering Consultants) (1954) – Western Niger delta. The Hague, 57 p.

—— (1959) – River studies and recommendations on improvement of Niger and Benue. Amsterdam, 1000 p.

—— (1961) – The waters of the Niger delta. The Hague 317 p.

Ocamb, R.D. (1961) – Growth faults of South Louisiana: Gulf Coast Assoc. Geol. Socs. Trans., 11, p. 139-175.

Oomkens, E. (1967) – Depositional sequences and sand distribution in a deltaic complex; A sedimentological investigation of the post-Glacial Rhone delta complex: Geol. en Mijnb., 46, p. 265-278.

Porrenga, D.H. (1967) – Glauconite and chamosite as depth indicators in the marine environment. Marine Geology, 5, p. 495-501.

Shelton, J.W. (1968) – Role of contemporaneous faulting during basinal subsidence: Am. Assoc. Petrol. Geol. Bull., 52, p. 414-419.

Short, K.C. and A.J. Stäuble (1967) – Outline of Geology of Niger Delta. Am. Assoc. Petrol. Geol. Bull., 51, p. 761-779.