Fig. 11.14: Sedimentation model of the Woodford floodplain.
12. Floodplain of the Study Area

12.1: Introduction:

The floodplain sediments are the upper part of the Holocene sedimentary sequence that accumulated within the basin during the Holocene sea-level transgression and subsequent stillstand. The basin-fill sequence evolved over thousands of years, from early Holocene time, from mud basin through fluvio-deltaic to fluvial phases (Chapter 4). At the broadest scale, development of the inner sedimentary basin of the lower Clarence River was controlled by the bedrock barrier, separating the fluvially-dominated inner basin from the marine-dominated outer basin. The inner basin is fully fluvial, with complex fluvial architecture comprised of a bifurcating main channel, an anabranch and several chute-channel systems. This chapter starts with a discussion of antecedent controls of the fluvial sequence; but primarily deals with the floodplain and the facies model that are representative of the fluvial processes and products.

12.2: Antecedent controls on the fluvial phase of basin infilling:

The locations of the channel zones on the present day floodplain probably are controlled, to some extent, by the locations of palaeo-fluvio-deltaic distributaries. Some channel zones on the Grafton and Tucabia floodplains, such as Deep Creek (Fig.12.1), may well be sites of palaeo-distributaries of the fluvio-deltaic phase that carried deltaic discharge into distal parts of the palaeo-bays within the inner basin. The straight channel zone within the Calliope floodplain may include paths followed by former deltaic channels towards the southern passage through the bedrock barrier. However, the channel zones as they occur today are more "superficial" in the sense that mid-Holocene deltaic and estuarine formations have largely been replaced by channel-zone sediments.

The depths of the channel-zone sediments as a whole are less than the present Clarence River, which indicates that the channel zones are secondary features, subordinate to the main Clarence channel and probably formed after its connections to two passages through the rock barrier were established. Thus, sedimentary bodies of the channel zones do not represent palaeochannel sediments of the palaeo Clarence River in its mid-Holocene deltaic phase. Further, the orientation of the channel zones suggest that
these originate as chutes and anabranches from the present Clarence River. The channel zones evolved in several stages, as shown by cross-cutting channels and splay in the Calliope floodplain, and some of the earliest floodplain channels appear to have been obliterated by later chute channel and floodplain sediments; for example, channel-zone sediments occur in the Woodford floodplain, in drill holes C3 and C6, in areas where surface channels now are absent. The present-day Clarence River, its channel zones and floodplain sediments represent a complex package within the Clarence inner basin, superimposed on and incised into the earlier estuarine and deltaic sediments. In some places, the relationship to deposits of the previous phase of delta building may be largely conformable (the main channel below Grafton, cf. figures 4.4 to 4.6 in Chapter 4), partially conformable (floodplain channel-zone sediments of the Grafton and Tucabia may sit on deeper narrower distributary channels, although no proof was found from the drill-hole data) or disconformable (proximal straight channel zone of the Woodford floodplain, Fig.12.2).

12.3 : Geomorphic characteristics :

The principal geomorphologic elements of the study area are mapped in figure 12.2. It is evident that the floodplain-channel zones are the most conspicuous features of the floodplain, covering about 40% of its total area, including most parts of the Grafton and Calliope floodplains and large areas of the Tucabia and Woodford floodplains. There are no abandoned meander bends or channels of a size comparable with the present Clarence River. The floodplain-channel zones, as described in Chapter 10, consist of geomorphic elements similar to those of the main channel such as channels, levees and leveed back swamps. The scale of these elements is smaller than those for the main channel, however; the floodplain channels essentially are chutes and splay, active during past major floods and both smaller and shallower than the main channel. Hence the floodplain of the study area can be said to have floodplains within floodplain, composed of floodplains of the channel zones nested within the floodplain of the study area as a whole. Sequential development of the subsidiary floodplain-channel zones is indicated by cross-cutting patterns of channels and splay; thus the Alumni channel complex
developed before the Calliope complex, which was succeeded by the Sweeneys channels (Fig.12.1).

Swamps are widespread on the Clarence floodplain, particularly in the Tucabia floodplain segment but are less extensive in the floodplain-channel zones than near the distal margins of the main floodplain. Swamp sedimentation is substantially slower than sedimentation on levees (main and secondary), proximal plains and platforms on the point-bar plains. Potentially, the elevation difference between the levees and distal swamps will increase through time, but is offset by differential compaction of underlying estuarine sediments, and by episodic sediment transport to swamps by flood overflows via distributary-channel breaches in levees. Floodplains behind the levees of the main channel usually constitute plains with flat surfaces, but sometimes traces of wide and shallow infilled channels can be seen on these plains. The plain of the Tucabia floodplain (Fig.12.2) has an irregular outer margin which reflects the outline of shallow channels in this area, such as Deep Creek. The floodplain of the study area has well developed levees along most of the main Clarence River and the South Arm (Fig.12.2) which are up to 4-5 metres higher than the lowest swamp surfaces, which are the lowest parts of the floodplain. The extent and height of these levees indicate lateral stability of the main channel; stability also is indicated by the point-bar plains, which are small in area and show few traces of recent activity.

The main channel, which is of low sinuosity (Fig.12.2), is both wider (550 to 600 metres) and deeper (the thalweg is about 10 metres or more below AHD) than the subsidiary chute and splay channels of the floodplain-channel zones. Inheritance of channels which formed during the transition from an estuarine to fluvial floodplain is reflected by bifurcation of the channel into north and south branches.

Tables 12.1 and 12.2 are summary descriptions of the different geomorphic units within the study area. All these geomorphic units, however, have been described in detail in Chapters 5 to 10. Table 12.1 summarises major floodplain elements, including floodplain segments, floodplain-channel zones, levees, plains and swamps within them.
Table 12.2 summarises characteristics of the geomorphic elements which are associated with the main channel, such as point-bar plains, levees, platforms and the channel itself.

12.4 : Sediment characteristics :

Sediments of the floodplain are grouped here into four broad genetic categories: (i) primary vertical-accretion deposits, (ii) primary lateral deposits, (iii) secondary vertical and (iv) secondary lateral deposits. Figure 12.3 shows the distribution of these groups (in figure 12.3, the secondary vertical and lateral are grouped together, and areas of primary lateral sediments usually have a cover of vertically accreted sediments). In order to distinguish between sediments derived directly from the main channel and those of the floodplain-channel zones, in morphostratigraphic terms, the deposits that are genetically related to the main channel are termed primary while those related to the floodplain-channel zones are termed secondary. Primary vertical-accretion deposits occur in about 60% of the total area of the floodplain, principally in proximal levees and plains near the main channel (mainly moderately to poorly sorted fine to very fine sands) and the distal swampy floodplains (mainly poorly sorted muds) (Fig.12.3). Primary lateral deposits occur near the main channel, principally in the basal parts of point-bar plains and beneath levees, and are mostly moderately well sorted medium to coarse sands. Except for active point bars, primary lateral deposits are covered by a veneer of vertically-accreted deposits. Secondary deposits of the floodplain-channel zones, cover about 40% of the total floodplain. Secondary lateral-accretion deposits are moderately sorted medium sands, which occur within the subsidiary channels, beneath the levees and in the channel splays, while secondary vertical deposits, which range from moderately to poorly sorted fine to very fine sands to poorly sorted muds, occur in the lower plains and swamps of the floodplain-channel zones. In certain parts of the Clarence floodplain, such as in the upstream region of the Tucabia floodplain segment, primary vertical-accretion deposits cover the entire floodplain, right from the main channel levee to the valley margin (Fig.12.3). In other parts of the Clarence floodplain, such as the Calliope floodplain segment, secondary deposits of floodplain-channel zones make up most areas of the floodplain segment.
Grain size analyses of the representative samples of lateral and vertical-accretion deposits were reported in Chapter 3, which showed that irrespective of origin, whether primary or secondary, lateral-accretion deposits differed from vertical-accretion deposits of levees and ridges, plains and swamps, each of which tends to have its own cluster of sediment characteristics.

12.5: Generalised Facies Models of Fluvial Deposits in the study area:

The Clarence River within the study area is laterally stable. Except for areas marginal to the main channel, which are covered by its levees and plains, the rest of the Clarence floodplain is either covered by floodplain-channel zones or swamps. Had there been no floodplain-channel zones, about 80% by area of the Clarence floodplain would be composed of swamps, whereas floodplain-channel zones and swamps each cover about 40% of the present floodplain (Fig. 12.2). Both floodplain-channel zones and primary swamp associations have characteristic facies attributes. The primary swamp association has the simpler facies ensemble, illustrated in figure 12.4 and 12.5, where proximal fine sands of main-channel levees pass laterally into distal swamp muds, all overlying estuarine deposits at relatively shallow depths (1.5 to 2 metres below AHD). In the floodplain-channel zones, on the other hand, vertical and lateral sediments (the latter often medium sand) alternate horizontally and interdigitate vertically, and secondary swamp mud often lies above and between elongated tracts of channel sand (Fig. 12.6 and 12.7). Furthermore, in these zones, the interface with underlying estuarine sediments is deeper (mostly about 3.5 metres but occasionally up to 7-8 metres below AHD), and more variable, than in the primary swamp zones.

12.6: Geomorphologic and sedimentary history of the fluvial system:

The geomorphic history of the lower Clarence fluvial system, since termination of the mid-Holocene estuarine phase, can be inferred from morpohostratigraphic relationship within and between the floodplain-channel zones and the primary floodplains and swamps. Immediately before the commencement of the present fluvial regime, the Clarence palaeo-valley was an estuary with an extended bay-head "slit-jetty" delta, and tidal deltas at its rock-barrier entrances were about to close with the bay-head
delta (Chapter 4, figure 4.5) (sedimentation phase E-1 of Fig.12.5 and 12.7). The fluvial regime commenced when the bifurcating main channel was established at its present location (sedimentation phase C-1) in the late Holocene time around 2,500 years B. P.. Since this event, levees, point-bar plains and swamps continued to aggrade through primary vertical deposits (phase V-1 of figure 12.5) during overbank floods, with gradual decrease of sediment size, from sands to muds, away from the main channel (Fig.12.4). The distal swamp deposits, in this case, conformably overlie the estuarine deposits.

Following establishment of the main channel, floodplain-channel zones with subsidiary channel-levee-plain complexes, were progressively incised as successive chute and splay complexes during overbank floods. Sequential changes are indicated by the relationships in figure 12.7 which shows that after the establishment of the main channel at its present position (phase C-1), secondary channel cutting and aggradation occurred (lateral phases L-1 and L-2 and vertical phases V-2 and V-3). Phase L-1 and V-2 represent sedimentation within the principal areas of the floodplain-channel zones whereas, phases L-2 and V-3 represent sedimentation within the overbank splay and floodchannel areas of these floodplain-channel zones. The sedimentation within floodplain-channel zones are controlled by their internal processes, largely independent of the processes of the main Clarence river although the ultimate sources of sediments into these subsidiary channel zones are from the main river. These chutes and splays are best developed in the Tucabia and Calliope floodplain segments and they depart from the main Clarence channel in a common trunk splay area (Fig. 12.1). The dimensions of these splay-channel complexes (up to several kilometres in width) suggest that they have repeatedly been altered by floods, while the near-perpendicular truncation of Calliope splay by Sweneeys splay suggests episodic capture of flow from one channel complex to the other. Deep Creek, on the other hand, is a single channel that may have formed earlier, as it appear to follow a branch of the bay-head delta that formed during the estuarine phase (Chapter 4).
12.7 Discussion:

The Clarence River and its floodplain in the inner estuarine basin is different from most fluvial river and floodplain systems, and from most estuarine channel and floodplain systems described from other parts of Australia. The main channel is unusually stable, with restricted point-bar plains that are unlike the scroll plains of meandering river; it also bifurcates downstream. Although the levees and swampy distal plains of the main channel resemble those of many normal fluvial rivers (such as those described by Rose et al., 1980, Nanson and Young, 1981, Brown, 1983) the floodplain is subdivided by subsidiary chute and splay-channel complexes to an unusual extent. The latter features, in particular, appear not to occur on the plains of the sand-barrier estuarine basins that are common elsewhere in NSW.

In that it comprises fine-textured sediments of vertical accumulation and coarser sediments of lateral accumulation, the Clarence floodplain system has sediment tracts that are comparable with those of normal fluvial systems, reviewed by Miall (1992), including those which have developed upon mid-Holocene estuarine deposits in different fluvio-tidal regimes including systems in north Australia and Papua New Guinea, described by Chappell (1993a). However, the spatial distribution, thickness variations and relationship with the underlying sediments differ from most facies patterns that have been schematically identified for other fluvial tracts. Consider, for example, the floodplain classification used by Nanson and Croke (1992), who divided floodplains into three classes: (i) high energy non-cohesive floodplains, (ii) medium energy non-cohesive floodplains and (iii) low energy cohesive floodplains (each class has a number of orders and suborders). The Clarence plain shares features with each class.

High energy non-cohesive floodplains, which are the most unstable, are characterised by high magnitude events, including stripping of fine grained floodplain sediments and replacement by gravels and coarse sands which, in turn, may become buried by finer-textured sediments. The medium-energy non-cohesive floodplain class of Nanson and Croke (1992) includes those of braided and meandering rivers, while the "low-energy cohesive floodplain" category includes laterally stable single channels and
anastomosed river floodplains. Braided river typically carry coarser sediments (sand, gravel and cobbles) than the Clarence, and do not concern us, but the meandering and low-energy cohesive floodplain systems have elements in common with the Clarence. The point-bar plains of the Clarence are genetically similar to meandering scroll bar, though much more restricted, while its near-stationary channel compares with stationary channels in low-energy floodplains. The systems of chutes, splays and subsidiary swamps have counterparts in anastomosed channel systems, which is a sub-class of low-energy floodplain in Nanson and Croke's schema, but the size and extent of such systems on the Clarence floodplain appear unusually high and suggest an affinity with the high energy floodplain category.

The floodplain-channel zones, which are the distinctive elements of the Clarence floodplain, thus have features in common with each type of floodplain identified by Nanson and Croke (1992) (except for those of braided rivers). The facies relationships in figure 12.7 characterise the complexity of the Clarence floodplain-channel zones; they show evidence of repeated high-energy overbank incision, stripping and infilling in the channel complexes, and differ from tracts of lateral sedimentation in meandering systems. The facies of the floodplain-channel zones can not be completely characterised in this thesis, and thereby contrasted with other types of floodplain systems, because sedimentary structures could not be identified by the augering and drilling techniques used here. However, the distinctive characteristics of the Clarence floodplain tract is shown by spatial relations and the extensiveness of the channel, levee and swamp sediments of the floodplain-channel zones.
Table-12.1: Forms of geomorphic units within floodplain areas.

1. Floodplain segments:

These are generally half circular to irregular in shape with a generally flattish surface and an overall tilt away from the main channel. They look continuous both laterally and longitudinally. Average widths of the floodplains are several kilometres. The dimensions of the floodplain segments can be variable.

2. Floodplain channel zones:

These are floodplains within the broader floodplain of the study area and formed by floodplain channels, which are not former channels of the main Clarence River. These zones can be several kilometres in lengths and width and they collectively cover about 40% of the Clarence floodplain within the study area. These floodplain channel zones have their own channels, levees, plains and swamps. Scales of overbank geomorphic units are directly relate to the scale of the adjacent channel.

2. Levee of the main and branch channels:

Channel marginal ridges, of variable longitudinal geometry, tend not to have abrupt breaks when observed in plan view. They are sometimes longitudinally discontinuous, with individual segments up to 5 km long, and few hundred metres wide. They show some variability of their dimensions in different parts of the flood plain.

3. Plain:

Generally elongated to irregular in shape, relatively featureless and flat topped with gentle slope away from the main channel. Several km long and few hundred metres to few kilometres wide in most cases. They show wide variation in shape and dimension.

4. Swamps:

They are low lands which often includes large number of wet lands. Gently sloping at the marginal parts. Mostly irregular in shape, often several km long and wide and shows variation in dimensions.
Table 12.2: Forms of different geomorphic units associated with Channel.

1. **Main channel**

   Nearly straight channel with few broad meanders. Depth of the thalweg of the channel is generally about 10m below AHD. The width of the channel is slightly variable, being between 500 to 600 metres. It is single channelled with stable anabranching rather than forming large number of within channel bars/islands.

2. **Southern branch channel**:

   Slightly sinuous. The width is variable between 150 to 200 metres. Becomes slightly narrower downstream.

3. **Point bar plains**:

   Arcuate or crescent shaped, dissected by smaller channels. Up to several kilometres wide at apex, extends up to 5 km in length around the bend and the highest part of the bar is about 4 to 5 metres above the normal water level in the adjacent channel.

4. **Levees on the bar plains**:

   Elongated mound of variable longitudinal geometry. Tends not to have abrupt breaks when observed in plan view. Up to several kilometres long and about 10's metres wide. Wide variation of dimension of these features can be observed.

5. **Platforms**:

   Mainly arcuate to irregular shaped. Mainly flat topped to slightly sloping towards marginal area. Up to several kilometres long and 100's of metres wide. Occasionally slightly sloping down stream.

6. **Chute channel**:

   Generally straight to slightly curved around the bend of the main channel. Predominantly single channel and occasionally bifurcated down stream. About 100 metres wide and several kilometers long. The width is variable at different localities.
Fig. 12.1: Major splay and channel areas of the Clarence inner-basin floodplain. Multiple-channel areas of the Calliope and Swneesys Creek is the trunk splay.
Fig. 12.3: Distribution of sediment groups in the floodplain of the study area. Primary deposits are genetically related to the main channel, while secondary deposits are related to the floodplain channel zones.
Fig. 12.4: Representative lateral cross section of the "swamp" model of geomorphologic and sedimentation history of the fluvial system within the Clarence inner basin.
Fig. 12.5: "Swamp" type model of geomorphologic and sedimentation history of the fluvial system of the Clarence inner basin.
Fig. 12.6: Representative lateral cross section of the “floodplain-channel zone” model of geomorphologic and sedimentation history of the fluvial system of the Clarence inner basin. Note: (i) fluvial-estuarine interface at 1.5 to 3.5 metres below AHD; occasionally it is up to 7 - 8 metres below AHD. (ii) The auger holes shown as very narrow columns immediately beneath channels in the straight channel zone are channel-filling muds and fine sands, significantly finer than adjacent sands of lateral accretion.
Fig. 12.7: "Floodplain-channel zone" model of geomorphologic and sedimentation history of the fluvial system of the Clarence inner basin.
13. Conclusions and Discussion

13.1: Introduction

This chapter has two main sections: conclusions, and discussion. The first of these sections provides, in summary form, the major results of this research project while the second compares these major features of the Clarence fluvio-estuarine basin with those described in the literature.

13.2: Conclusions

The Clarence River within the study area is laterally stable, except for localised migration where point-bar plains have formed. Vertical accretion during overbank flooding has formed levees and plains in the proximal parts of the floodplain and has contributed to slow filling of swamps in its central and distal parts. In these situations, sediments are moderately to well sorted silts and fine sands in the proximal parts of the floodplain and are finer textured away from the main channel. However, about 40% of the Clarence floodplain is composed of floodplain-channel zones, which are not palaeochannels of the present Clarence River but are chute-channel complexes formed during catastrophic floods. These zones include channels bordered by levees, plains and swamps; the channel-zone sediments vary between these elements in much the same way as in the main channel and its floodplain system. Owing to their composite nature, the floodplain-channel zones are regarded as separate floodplains nested within the broader floodplain of the Clarence River.

In distal parts of the floodplain, where overbank sediments have been deposited, fluvial sediments conformably overlie estuarine sediments at shallow depths (0 - 2 metres below AHD). In comparison, the floodplain-channel zones have fluvial sediments to depths of 3-7 metres below AHD, disconformable over estuarine sediments into which the channel zones are incised. Throughout the lower Clarence basin, Holocene estuarine sediments, which underly the fluvial deposits, accumulated largely during post-glacial sea-level rise. The estuarine basin contracted seaward, in
later Holocene times, and was overtaken by sediments and landforms of the fluvial system.

The lowland basin of the Clarence River comprises two major compartments, referred to throughout this thesis as the inner and outer basins, separated by a bedrock barrier. The outer basin is impounded by a Holocene coastal sand barrier anchored to bedrock highs, similar to other estuarine basins in southeastern Australia; amongst these the lower Clarence is distinctive, however, through being both strongly compartmentalised and largely infilled with Holocene sediment. The floodplain geomorphology of the inner basin with its multiple, subsidiary floodplain-channel systems, is different from the estuarine floodplains of the outer Clarence basin and most other estuarine basins in New South Wales, which typically have broad, simple swampy plains and estuarine backswamps. Furthermore, the floodplain system of the inner basin does not resemble any of the common forms of purely fluvial floodplain; its channel is not simply meandering, braided or anastomosing, but is characterised by multiple channels and splays, and the depth to which fluvial sediments overlie or incise into the underlying estuarine deposits varies to an unusual degree.

It is suggested that the Holocene fluvio-estuarine morphostratigraphy of the lower Clarence River, which is a distinctive variant within the broad class of Holocene estuarine barrier-basins described from New South Wales by Roy (1984b) and others (Roy et al., 1994; Nichols et al., 1994), owes its character to its being in the unusual setting of a relatively large river entering a strongly compartmentalised estuarine basin. Each component of the system, during its Holocene evolution, has a counterpart elsewhere but the total ensemble of mid-Holocene mud basins, tidal deltas and an elongated bay-head delta, together with the late Holocene floodplain and channel complex, appears to be characteristic of the Clarence alone.

In terms of systematic sedimentary geology, this study of the Holocene Clarence basin confirms the general models of sand-barrier estuarine basins on the high energy coast of NSW that have been developed by Roy at al. (1994), but also shows that the characteristics of fluvial sediment tracts within these basins depend on
the magnitude of the fluvial input. The Clarence inner basin, in which tidal influence is doubly reduced by the outer Holocene sand barrier and the inner bedrock barrier, receives the largest river entering the NSW coast; both factors contribute to the formation of the Holocene fluvio-deltaic sediment tract which, with its subsidiary channel systems, is more complex than most other estuarine plains in southeast Australia.

The evolution of the Holocene Clarence basin is summarised as follows. A large mud basin developed landwards of the bedrock barrier, during early Holocene sea-level rise, and sand barriers seawards of the present coast moved onshore, during the marine transgression. Sedimentation in the inner basin was dominantly pro-delta mud, stemming from an elongated bay-head "silt-jetty" delta of the palaeo-Clarence River. A tidal delta appears to have entered through the northern entrance, stemming from the outer basin which developed when sand barriers accreted to form the present coastline. Within the inner basin, the prograding silt-jetty delta eventually closed with the rock barrier, dividing a near-freshwater southern subbasin and a northern brackish subbasin. Estuarine deposits within the inner basin were subsequently incised and stripped, at places, by fluvial flood-channels, although the main Clarence channel and its South Arm appear to have remained almost stable laterally, for the last 2,000 years or so. Direct fluvio-deltaic sediment discharge, mostly fine sand and mud, into the outer basin started at about the time when permanent channels were established within the inner basin, which combined with marine sand to partially infill the outer basin although a large lagoon still exists in the south. Chute and splay channels do not occur in the outer basin floodplain, which resembles estuarine floodplains elsewhere in NSW. In summary, the inner basin and its sedimentary tracts, both early-mid Holocene estuarine and late Holocene fluvial, are dominated by fluvial sediments and channel processes; the outer basin is dominated by marine sediments, with admixture of fluvial mud, and by estuarine channel and lagoon processes.
13.3. Discussion

The contribution of this study to the broader body of knowledge concerned with fluvio-estuarine sedimentary sequences can be demonstrated by comparing the Clarence system with others in southeastern Australia and elsewhere in the world.

13.3.1 Comparison of the Clarence with other Holocene estuarine basins in southeastern Australia

Holocene estuarine basins in New South Wales range from drowned valley harbours, typically with tidal-delta sand bodies at their entrances through large river-fed, tidal lagoons impounded but not completely enclosed by coastal sand barriers, through to saline coastal lakes, impounded by coastal sand barriers which are only ephemerally breached (Roy, 1984b). All have at least some of the following features -- transgressive sediment tracts at the base overlying a late Pleistocene palaeo-land surface, a coastal sand barrier of one of the types (regressive, transgressive or stationary) previewed by Roy et al. (1994), a back-barrier "mud basin" sediment body, often partly overlain by transgressive barrier sands, a tidal-delta sediment tract and a fluvio-estuarine morphostratigraphic tract overlying the various estuarine sediment bodies. These Holocene ensembles, reviewed in Chapter 1 on the basis of previous work by Roy (1984b), Roy et al. (1994) and others (Figs. 1.1b, 1.2, 1.3), were developed during post-glacial sea-level rise and the subsequent still stand and, as such, represent the upper, proximal parts of transgressive and highstand-systems tracts, which developed on the shelves of southeastern Australia during the Holocene (cf. Chapter 1).

The Clarence Holocene estuarine basin includes most of the above elements but differs from most others in southeastern Australia in that it is partitioned by a bedrock barrier into two subsidiary basins, the inner and the outer, which differ in both their transgressive and stillstand sequences. In common with the other relatively large rivers which have estuarine basins in coastal New South Wales (e.g. the Hunter, and Shoalhaven), the lower Clarence is dominated by fluvio-estuarine floodplains, overlying estuarine sediments, deposited during post-glacial transgression and the subsequent stillstand. The lower to mid Holocene mud basin sediment of the inner basin, including
marine sands intruding through tidal-delta sedimentation at the northern bedrock passage, resemble mud-basin sediment tracts of Lake Macquarie and Tugerrah Lake, described by Roy (1984b), although the Clarence inner basin is larger, and infilling of the estuarine mud basin was achieved early, consistent with the fact that the Clarence is the largest river reaching the southeast Australian coast. Deltaic "silt-jetty" sedimentation in the inner basin, although not completely identified from the drill-hole data, appears to have contributed significantly to mid-Holocene filling of the inner basin, as well as eventually partitioning it into northern and southern compartments of brackish and fresh water, respectively.

Other southeastern Australian estuarine basins, with relatively large rivers, have geometries that are different from either the inner or the outer basin of the Clarence, and thus are less completely filled with sediment or have different facies associations. The degree to which a basin is filled largely reflects the volume impounded by its barriers, and the rates at which fluvial and estuarine sediments enter the basin. To a large extent, marine sediments enter during later stages of the post-glacial transgression, before coastal sand barriers are fully developed, and continue to enter, after that, by tidal delta sedimentation at the estuary entrance; landward of the tidal delta, sedimentation is dominantly from a fluvial source (Roy et al., 1994). In the case of very large basins, such as the Gippsland Lakes basin, which is impounded by a coastal barrier more than 60 kilometres long (Fig. 13.1a), the volume is so large relative to fluvial input that the basin remains as unfilled extensive lakes. By comparison, both basins of the Clarence were nearly filled with estuarine sediments, the inner basin before the outer, before late Holocene times. The outer basin is impounded by a coastal barrier which is short, relatively to the Gippsland case; the inner basin is almost completely barred by bedrock. The total basin volume is perhaps five to eight times smaller than Gippsland but the fluvial inputs are fairly similar; hence, the Clarence basin is much more completely filled.

These generalisations could be taken further and tested against other systems in southeast Australia, given more precise data on basin volumes, fluvial sediment inputs,
and coastal barrier and tidal delta evolution. To do this is beyond the scope of this thesis. However, the effects of basin geometry upon sediment-facies distribution, within basins at about the same stage of sediment infilling, can be seen by comparing the Clarence and the Shoalhaven systems.

The Shoalhaven fluvio-estuarine basin, in southern NSW, is at the estuarine end of the Shoalhaven River, which diverges into deltaic channels near its entrance, with coastal sand barriers to the north and south. Prior channels of the Shoalhaven and the smaller Broughton Creek have been mapped from abandoned levees and channel deposits (Roy, 1994) (Fig.13.1b). The fluvio-estuarine plain is composed of mostly sandy mud inland near its apex, and of muddy sand, near the entrance; these deposits overlie fine grained mud basin deposits. In general terms, the Shoalhaven system near the coast resembles the Clarence outer basin, with its coastal sand barrier, multiple estuarine channels, tidal delta deposits and underlying estuarine shelly sands and muddy sands. Nearer its apex, the Shoalhaven system resembles the Clarence inner basin, with fluvial, fluvio-deltaic and swamp sediments incised into or overlying mid-Holocene muddy estuarine deposits. However, the Shoalhaven has no counterpart of the subsidiary channel floodplain tracts that are so prominent in the Clarence inner basin (Fig.13.1c), nor does it contain interior tidal delta deposits such as occur at the northern passage through the Clarence bedrock barrier.

Finally the relationship between the Holocene fluvio-estuarine deposits of the Clarence and those of the shelf, immediately offshore deserve some comments. Holocene estuarine basins of southeast Australia represent proximal transgressive and highstand-systems tracts, overlying a type-1 sequence boundary (the buried Pleistocene land surface), as discussed in Chapter 1 (cf. figure 1.1a and 1.1b). However, the relationships between the fluvio-estuarine tracts and shelf sediments offshore are less simple than suggested by sequence stratigraphy schemas such as that shown in figure 1.1a. Roy et al. (1992, 1994) showed that late Pleistocene sand bodies of the inner shelf are not continuous, but exchange with coastal sand bodies at different sea-level stages, and that Holocene coastal barriers are derived from sands stripped from the shelves during
transgression, rather than being the onshore part of continuous tracts of Holocene shelf sediment. The Clarence system, although not tested by offshore drilling, is likely to resemble the Forster-Tuncurry system described by Roy et al. (1992, 1994), and hence is unlikely to have continuity with an offshore Holocene tract.

13.3.2: Comparison with Holocene fluvio-estuarine sediment tracts in other coastal and fluvial regimes.

The Holocene estuarine basin of the lower Clarence River is clearly a variant of the estuarine systems of southeastern Australia, which have been described by Roy et al. (1994) and others, and the bedrock-barred inner basin of the Clarence, with its complex fluvial sediment tract, is different from the more common sand-barrier estuaries. Holocene estuarine basins that have extensive fluvial or fluvio-deltaic sediment tracts overlying muddy estuarine sediment bodies occur in other regions, with different tidal regimes and different types of sediment sources. Some of the similarities and differences, and their causes, between the Holocene sediment tracts of the Clarence inner basin and systems elsewhere are now reviewed.

Reinson (1992) suggested that estuarine sediment tracts vary more with the volume of the estuarine tidal prism, which depends largely on external tidal range but partly on the size of the estuarine entrance, than with other boundary conditions. Thus, micro-tidal to lower meso-tidal sand-barrier estuaries on wave-dominated coasts elsewhere in the world all tend to resemble the mud-basin systems of coastal NSW, with upwards-shallowing sediment tracts that have mud-basin lagoonal sediments overlain by tidal delta or sand-barrier sands (Reinson, 1984, 1992). The relative importance of tidal versus river dominance in determining estuarine sedimentation patterns (including deltaic estuaries) was emphasised further by Chappell and Woodroffe (1994), who also stress that the relative magnitude of fluvial sediment input has a significant effect on large-scale facies relationships. The magnitude of the fluvial input, relative to tidal, varies with catchment size, tectonic activity and climate.
The effects of these factors -- tidal prism and fluvial sediment input -- are now summarised, to show why the Clarence inner basin differs from other Holocene estuarine sediment tracts that share the same major facies groups as the Clarence. Comparisons will be made with macro-tidal mud-dominated systems in north Australia, whose catchments yield sediments of about the same type and at about the same rate as the Clarence, and with the Sepik Basin in Papua New Guinea, which, like the inner Clarence basin, is rock-barred and micro-tidal, but whose catchment has a very high sediment yield.

The Daly River lowland basin is a typical north Australian macro-tidal estuary, with an extensive mid-Holocene estuarine mud-sediment tract overlain by fluvial deposits. The latter include channel deposits incised into the estuarine sediments and extensive distal swamp sediments conformably over the estuarine sediments. Both the Clarence and Daly are large river systems draining moderately rugged catchments. However, as shown by Chappell (1993a), the Daly fluvio-estuarine basin is macro-tidal and the lower to mid-Holocene estuarine sediments are intertidal, organic mangrove muds that accumulated while keeping pace with rising sea level (a mid-Holocene "big swamp", in the terminology of Woodroffe et al., 1986), which is quite different from the subtidal mud basin sedimentation of the Clarence inner basin. Rather similar contrasts exist between micro-tidal systems such as the Gironde (Reinson, 1992). Furthermore, the Daly channel is highly unstable but its channel sediments are confined to single, broad meander belt with lateral-accretion scroll-bar deposits (Chappell, 1993a), which is quite different from the subsidiary floodplain-channel zone sediment tracts, associated with chutes and splay, of the Clarence inner basin. Tidal processes are basically responsible for the dominant features of the Daly system. Sediment supply for the vertically accreted intertidal "big swamp" sedimentation was mud, derived from the seaward direction, pumped by macro-tidal flows (Chappell and Woodroffe, 1994). This contrasts with the fluvial input of mud to the Clarence inner basin. The meander belt, formed through very active migration of point bars associated with sinuous estuarine meanders, has developed through tidal transport of estuarine sand in the upstream direction, which sustains high sediment loads and causes the tidal river to resemble a fluvial meandering river. The
Clarence, with its relatively low sediment load, but subject to occasional large floods in a bifurcating estuarine channel, appears to burst readily overbank into chutes and splays, thus reworking its floodplain sediments differently from the Daly.

The Sepik basin has a large mud-basin sediment body underneath the fluvial sediments. In most places of the basin, which are covered by widespread swamps, the fluvial deposits conformably overlie those of estuarine origin, whereas in relatively narrow meander tracts of the main Sepik channel and its tributaries, sandy fluvial deposits incise into the underlying estuarine sediment bodies. Because the Sepik River has a very high sediment discharge rate, and as the coast has micro-tidal conditions, the mud basin of the Holocene Sepik estuary was filled rapidly by the muddy sedimentation of fluvio-deltaic origin rather than marine origin. The source of the Sepik mud basin sediments is similar to that of the Clarence inner basin. However, the Holocene basin-fill sequence of the Sepik is more like the Daly estuarine basin in that both have mud-basin sediment bodies overlain by dominantly muddy fluvial sediments with limited sandy meander tracts whereas the Clarence inner basin has widespread sandy fluvial deposits of floodplain channel-splay complexes overlying estuarine muds.

**Economic implications of the Clarence lowland basin study:**

The low-organic estuarine muds of the Clarence inner basin is unlikely act as good source rock for hydrocarbon generation. However, the basin has large volumes of sandy bodies, deposited in the form of floodplain channel-splay complexes, within the basin which could act as potential reservoirs. The general concept of low reservoir potential of fine-grained floodplain deposits of anastomosed or laterally stable single-channel rivers, need to be reviewed because of the fact that the Clarence floodplain, which has formed from a laterally stable channel, has such a large distribution of potential reservoir rocks. So, a hypothetical basin with basal organic rich estuarine muds, like that of the Daly basin, overlain by fluvial facies like that of the Clarence inner basin, could act as good hydrocarbon generating sedimentary sequence.
Fig. 13.1: Barrier impounded Holocene fluvo-estuarine basins of southeast Australia. (a) The Gippsland Lakes (After Bird, 1965). (b) The Shoalhaven basin (After Roy, 1994). Index: 1 = palaeo levee channel tracts, 2 = present-day channel tract, 3 = plain and swamp, 4 = basin mud. (c) Clarence fluvo-estuarine basin. Index: 1 = fluvial channel plain, 2 = floodplain (swamps, flat floodplain, lake shores, tidal islands etc.)
References


